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Airframes and Engines Division
Aeronautical and Maritime Research Laboratory

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ABSTRACT

On August 20, 1998 a United States Marine Corps F/A-18 aircraft crashed at Delamere bombing range in the Northern Territory. AMRL was invited to aid in the investigation by trialing the AMRL wreckage mapping and analysis equipment at the site. The equipment was used to plot and record all wreckage of interest. Maps of the wreckage were produced on site and handed over to the accident investigation team. These rapidly produced maps, along with the experience brought with the AMRL investigators with on site wreckage examination, greatly aided the accident investigation team to expedite recovery of the site and clarify many aspects of the accident. To this end, the trial of the equipment was very successful. Following this trial, the data was used to explore the capabilities of other visualisation software, and its relevance to accident investigation. The results of this are presented during the discussion of the accident.

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Executive Summary

On August 20, 1998 a United States Marine Corps F/A-18 aircraft crashed at RAAF Delamere bombing range in the Northern Territory. AMRL was invited to aid in the investigation by trialing AMRL Global Positioning System (GPS) based wreckage mapping and analysis equipment at this site. The equipment was used to plot and record all wreckage of interest. Maps of the wreckage were produced on site and handed over to the accident investigation team. The availability of these maps along with the on-site wreckage examination greatly aided the accident investigation team in speeding up recovery of the site and clarifying many aspects of the accident. To this end, the trial of the equipment was very successful. Following this trial, the data was used to explore the capabilities of a Geographic Information System (GIS) and other visualisation software, and its relevance to aircraft accident investigation.

The maps produced after manipulation were used to assess the flight path of the accident aircraft just prior to impact. During this exercise, software modification requirements were identified. Where possible, these will be incorporated into the system to ease data collection and manipulation difficulties.

The main findings of the analysis of the data collected by AMRL along with some wreckage evidence were:

(a) The United States Marine Core F/A-18 impacted the ground with a bank angle of about 90°, left wing down.

(b) The aircraft impacted the ground at about 40° to the ground with little or no angle of attack.

(c) The wreckage was mostly ejected from the hole at about the same angle as it entered ie. it was 'reflected'.

(d) There was no evidence that suggest pilot input and any control commands that would indicate that he had become aware of the impending impact.

Findings specific to the equipment and software:

(a) The GPS system performed satisfactorily on site at Delamere.

(b) The GIS software will allow extensive data manipulation and will allow the inclusion of, or linking to, of numerous other sources of data.

(c) Several aspects of this software are needlessly complicated or are not particularly focused on the AMRL requirements for ease of use – these features will need to be altered where possible.
(d) The 3D software trialed is at present capable of displaying images which will considerably enhance visualisation of aircraft accidents and the events leading up to them.
(e) The 3D software trialed is difficult to manipulate although simple model display and movement are reasonably easy.

Authors

Simon Barter
Airframes and Engines Division

Simon Barter, Senior Professional Officer. Graduated from RMIT with a Diploma of Applied Science in Secondary Metallurgy (1982) and a Graduate Diploma in Surface Finishing and Corrosion Control (1987), both gained though part-time study while being employed at AMRL. He has been mostly involved with the metallurgical investigation of aircraft structures and components. These studies have included quantitative fractographic studies on Macchi, F111 and F/A-18 aircraft and research into fatigue crack growth in aircraft metals. His involvement in the investigation of numerous aircraft accidents has been the highlight of this work, having completed the Aircraft Accident Investigation course held at Cranfield Aviation Safety Centre. He now works in the Fatigue and Fracture Detection and Assessment area undertaking investigations into fatigue and fracture, aircraft accident investigation techniques and oxygen system materials compatibility.

Loris Molent
Airframes and Engines Division

Loris Molent; Senior Research Scientist. Mr. Molent graduated in 1983 with a Bachelor of Engineering (Aeronautical). Since commencing employment at the then Aeronautical Research Laboratories in 1984, Mr Molent has worked in the fields of aircraft structural integrity, structural and fatigue testing, aircraft accident investigation and aircraft vulnerability. He has numerous publications in these technical areas. He has been attached to both the Civil Aviation Department (1985) and the US Navy (NAVAIR, 1990-1991) as an airworthiness engineer. Mr Molent is currently a Senior Research Scientist and task manager F/A-18 Life Assessment, at the Aeronautical and Maritime Research Laboratory (AMRL). Mr Molent is the Structures representative on the AMRL Aircraft Accident Investigation Committee.

Contents

1. Introduction

During the investigation of aircraft mishaps, identification and mapping of wreckage is usually required prior to its collection (and, if necessary, detailed examination) [1, 2, 3, 4 & 5]. This recording phase can be time-consuming and very expensive in resources, particularly when the wreckage is spread widely. Apart from the required surveyors, a team conversant with the aircraft's structure, a photographer, and one of the investigators may be necessary to produce useful data. This could take considerable time depending on the accuracy required and the number of parts to be mapped. Accurate mapping by conventional methods may restrict mapping to 50 or less points a day, followed by data plotting and map generation away from the accident site.

The time consumed and expense, were well illustrated during AMRL's involvement in the accident investigation of two Australian Army Blackhawk aircraft at High Range near Townsville during June 1996. In this case, a group of four surveyors was used along with two personnel familiar with the aircraft structure, a photographer and one of the investigation team. The process in the field was very slow and considerable time elapsed between the initiation of the wreckage survey, and the production of useable maps and the collection of the parts of interest. Indeed parts were collected and analysed, and reports were written well before wreckage maps were generated and made available to the investigators.

As a direct result of the difficulties encountered with the Black Hawk investigation, AMRL began the development of a rapid wreckage mapping system. This had become possible as a result of the Global Positioning System (GPS) being assembled by the US Department of Defense, and the development of mapping equipment using GPS signals, by commercial surveying instrument manufacturers. Other developments include the introduction of reasonably priced medium-resolution digital cameras, and the rapid rise in portable computing power and Geographic Information Systems (GIS) software, which are geographic coded (spatial) data bases.

Although the use of GPS at accident scenes is not new, when fully developed and refined, the system trialed at this accident will provide considerably greater, almost instantaneous readouts of wreckage maps in any format desired. The accuracy will be sub-metre and may be considerably better than this in a relative sense (relative position of points at a site).

Prior to field trial, the system was operational, although limited fieldwork had been carried out and only an exploration of the software had been undertaken. In order to identify the strengths and weaknesses of the system and to more fully expose the capabilities of the software it was necessary for AMRL to trial the equipment in the field. It was particularly important to gain sufficient high quality data to test the software fully. To this end two trials at accidents sites have been completed – the accident to an Eurocopter Tiger aircraft and an F/A-18 aircraft. The F/A-18 aircraft accident is the primary subject of this paper.

1.1 The accident

On the night of August 20, 1998 a United States Marine Corps (USMC) F/A-18 aircraft BUNO 163743 crashed at Delamere bombing range in the Northern Territory. The aircraft, one of two in the formation, was carrying out a night bombing mission with practice bombs.

The Delamere range consists of a number of 'raked' ranges for practice bombs and high explosive weapons. The aircraft impacted the ground about 50m from the target on one (western range) of the two raked practice bomb ranges situated adjacent to the Range facilities. The target for the mission in question was about 1100m from the range control tower. Video cameras and the manned control tower monitor the two practice-bomb ranges.

The night of the accident was moonless and a small fire lighted the target, an old Army Tank. The incident aircraft approached the designated target from the south. It was observed to be lower than expected such that observers believed that the aircraft had missed the normal approach and would go round. Shortly after seeing this aircraft to the South of the control tower, the observers altered their attention to the second of the two aircraft. At about this time a radio communication from the first aircraft indicated that he was about to release his weapons. The tower crew immediately started the videotape to monitor the bombing run. At this time a large explosion and flash was observed and the tower crew took shelter as they thought that a high explosive weapon had detonated on the range. It later became apparent that the explosion had been caused by the first aircraft impacting the ground close to the designated target on the western range. A review of the videotape revealed only the latter part of the explosion, with most of the ejected debris on a downward path. Since the observers' attention had been directed elsewhere, and the video had not recorded the events just prior to impact, the aircraft attitude, the ground impact were unwitnessed.

After the range alerted RAAF base Tindal and informed the USMC, the USMC formed an investigation team. The Delamere range is about 150km SouthWest of Katherine, or approximately 450km South of Darwin. The Australian Defence Force Directorate of Flying Safety (DFS-ADF) was also alerted. DFS-ADF sent an observer to liase with, and help the USMC team where necessary, and the USN sent an USMC aircraft accident investigator specialist, from the US Naval Safety Center to head the investigation. Boeing also sent a company representative to observe the investigation. The DFS-ADF investigator advised the USN team that the AMRL GPS wreckage mapping equipment would be useful at this accident. The USMC OIC was initially hesitant about using the AMRL system, until it was pointed out that detailed maps of the wreckage site would be produced at no cost to the USMC, and presented in a short time frame. The USMC OIC then cancelled surveying contractors because of the expense and their slowness to react due to the remoteness of the accident location. The AMRL team arrived 3 days after the accident, by which time most of the wreckage had been found.

2. Introduction to GPS

Before going into the detailed results of the mapping efforts and the analysis of the data it is worth discussing the GPS, system and its strengths and weaknesses in relation to mapping items on the earths surface.

The GPS is a satellite-based system operated by the United States Department of Defense (US DoD). GPS provides an all-weather, worldwide, 24-hour service, which can be used for

calculating positions and time. To make this system available to unlimited users, a passive ranging method called pseudoranging is used [6, 7 & 8]. The satellites are active (transmit) and the user's units are passive (receive). The satellite transmissions enable computation of the user's position and velocity 'relative' to a spheroid Datum (model of the earth's surface). Positioning accuracy is attainable from 1 cm to 100 m, depending on the type of receiver used, antenna dynamics, number and position of the satellites in view, mode of operation and the processing (error correction) techniques employed by the user.

GPS, as a military system is intentionally degraded (Selective Availability (SA)) from achieving the highest positioning accuracy for a system relying on the GPS satellite data alone. The growing demand for civil use of this highly capable system has encouraged the civil community to add other data and functions to create a system that gives high, RELATIVE positioning accuracy.

The Global Positioning System gives a user their position in all areas of the world. However, real world ABSOLUTE positioning is extremely complex. Further information may be found in Reference 9.

The spheroid Datum used by the GPS system is the World Geodetic datum or System (WGS). The positions given by the GPS unit are referenced to this model of the earth's surface, rather than the actual surface of the earth. The earth is in fact a very complex shape that is not easily modelled. The WGS uses the centre of the earth's mass as its origin (geocentric) and three axes (Cartesian coordinate system) from that origin to define alignment. The latest WGS datum was established by using observations from satellites orbiting the earth over a long time, and is therefore quite accurate and recent– promulgated in 1984 and therefore known as WGS-84.

2.1 How the GPS system works

The following is a brief summary of how GPS works, more information may be found in reference 9.

Exact coordinates can be calculated for any position on earth by measuring the distance from a group of satellites to that position. The satellites act as precise reference points. Assuming the distance from one satellite is known the position can be narrowed down to the surface of a sphere surrounding that satellite. If the distance from a second satellite is also known, this narrows the intersection to a circle. By adding a third satellite, the position is narrowed to one of two points. One of these positions is disregarded because it is an unlikely answer. By knowing how far the position is from any three satellites, the coordinates can be calculated.

In practice, to solve for X, Y, Z, and time, four satellites are needed. The fourth measurement narrows the position down to one point, as the intersection of four spheres is one point. This is shown schematically in Figure 1

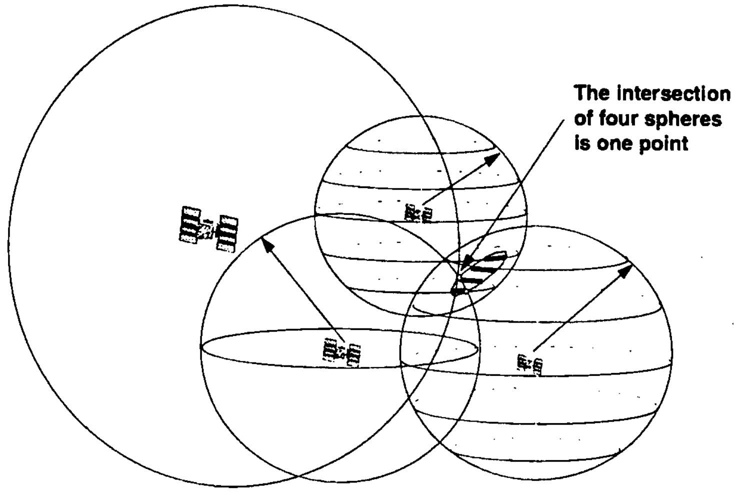

Figure 1 *Using satellite ranging to establish a receiver's position in space. Four satellites are needed to produce a single point solution. (From Reference 6)*

Accordingly, when GPS data is collected in the field, four satellites must be in view for three-dimensional data and the receiver must have four GPS channels or be able to sequence among four satellites.

2.2 Errors

GPS accuracy depends on many factors, one of which is the geometrical relation between the satellites tracked ie. Closely spaced satellites give poor discrimination of position. Poorly positioned satellites can introduce performance degradation called Dilution of Precision (DOP).

This will multiply the effect of any other errors in the ranges, such as those caused by atmospheric conditions (ionosphere, troposphere), multipath reflections, satellite orbit errors, receiver noise, satellite clock errors, and Selective Availability. These errors are more fully discussed below.

2.2.1 DOP

As satellites become more closely grouped in the sky the accuracy of the positions calculated decreases. To prevent this, tracking more that 4 satellites allows the receiver unit to select the best positioned satellites to produce the best accuracy. High quality receivers are usually configurable to reject positions taken when satellites are in poor positions.

2.2.2 Ionospheric and atmospheric delays

The distance calculations assume the GPS signal travels at a constant speed, the speed of light. Unfortunately, the speed of light is constant only in a vacuum. Once the GPS signal enters the ionosphere (140 to 200 km above the earth's surface) and the troposphere (our weather) the signal slows down, resulting in incorrect distance calculations. High quality GPS receivers perform some corrections for these delays, or may use comparisons between the two frequencies transmitted to correct for these delays.

2.2.3 Receiver and satellite clock errors and satellite position errors

Atomic clock and satellite orbit errors can occur, but are minor and are adjusted by the US DoD from their monitor stations.

2.2.4 Multipath interference

This occurs when the signal is reflected off other objects at or near the earth's surface. The reflected signal interferes with the straight-line signal. Advanced signal processing and well-designed antennas help minimise this. Typically, a ground-plane antenna is used for high accuracy positioning. Masking out multipath interference in hand held GPS units (with integral antenna) is more difficult.

2.2.5 Selective Availability

Due to the performance that can be achieved by tracking the GPS signals, the US DoD introduced a significant source of error called SA. SA is an artificial degradation of the satellite signal's synchronisation and orbital information. It causes errors in a GPS position of up to 100 meters (2drms[1]). SA can be removed using a technique called differential correction.

2.2.6 Differential Correction

Differential correction is a technique that greatly increases the accuracy of the collected GPS data. It involves using a receiver at a known location, the base station, and collecting GPS positions at unknown locations with other receivers (often referred to as "rovers").

The data collected at the known site is used to determine what errors are contained in the satellite data by comparing the calculated position against the known position of the base station. The information from the base station is then applied to the data collected by the rovers and the offset differences are used to remove errors from the positions. To do this the base station position needs to be known very accurately as differential correction position accuracy depends on the accuracy of the coordinates of the base station.

2.2.7 Real-Time Differential Correction

In real-time differential GPS, the base station calculates and broadcasts (through radio signals) the error for each satellite as it receives the data. Since the errors due to SA, satellite orbital and clock inconsistencies, and atmospheric effects will be similar for receivers tracking the same satellites through similar regions of the sky, all of these errors can be virtually eliminated. The degree to which this can be achieved is dependent on how close the two receivers are as both the base station and the rover must track the same satellites. Typically, error increases by 1 in 10^6 ie. 1m for 1000km, since tracking a satellite from two different positions will result in slightly different errors (path through the atmosphere, satellite orientation etc.). Usually correction

[1] Since the position given by the roving receiver is an estimate calculated from the pseudoranges taking into account any corrections for errors, the result is a probability position. Typically, this is denoted as either rms or 2drms, which refers to the number of standard deviations from the mean for that position ie. Rms is the probability that the position will be within a stated diameter 68% of the time, 2drms – 95% of the time and 3drms – 99% of the time. GPS accuracy is usually stated for the 2drms case.

services recommend that the rover should be limited to 500km from a base station. The correction data is received by the rover from either a satellite link or a ground based radio link. The rover applies the correction to the position it is calculating, resulting in a differentially corrected position. These corrected positions can be saved to a file in the data collector, and may be used immediately to generate, or update accurate maps in a GIS package.

The differential correction used in the AMRL system is realtime. If the connection to the realtime differential correction data is lost at a site, the data collected at a site can be postprocessed. This is achieved by using the data recorded at the base station, as long as that data is collected at the same time from the same satellites.

3. The GPS Mapping System Components

To create maps using GPS equipment it is necessary to log data, correct that data and display the data in a suitable format. The AMRL system includes a DGPS receiver and antenna, and a data logger for collecting GPS data in the field. To this are added a digital camera and a portable computer with software to program the data logger, extract the data and map the data. Also included is software to produce interactive maps that can contain image and other data (such CAD data) aimed at improving the analysis of an accident at as early a stage in the investigation as possible.

3.1 The receiver

GPS receivers are usually classified by the number of "channels" they have. They may calculate positions as often as once per second and provide accuracy from cm to tens of meters with differential correction processing and up to 100m without. The receivers vary in size, weight, and number of positions they store in their data collectors. The unit used by AMRL is a Trimble ProXRS receiver with 12 GPS channels and a multi-channel correction receiver. All these receiver channels are contained in a single box and use a single multi-element antenna, carried in, and mounted on, a backpack. For the investigation discussed here, differential correction data was supplied from a base station in Darwin and transmitted to the GPS receiver at Delamere via a telecommunications satellite. Being approximately 450km from the base station the relative (to WGS84) positioning accuracy was degraded by about 0.45m, which combined with the inherent accuracy of the GPS receiver gave a total positioning accuracy of submetre (2drms). Two closely positioned points taken at considerably different time could be separated by the error stated for the receiver, whereas the same positions taken one after the other (with little <u>time</u> in between) will be positioned, relative to each other, within centimetres. This is achievable since the errors (from satellite motion), for closely spaced points (in time) are virtually the same.

The approximate position of the accident site is shown in Figure 2, along with the 500km and 1000km radius lines from the base station in Darwin. The site is situated on a large plain covered with low trees and scrub. These types of conditions are ideal for good GPS reception.

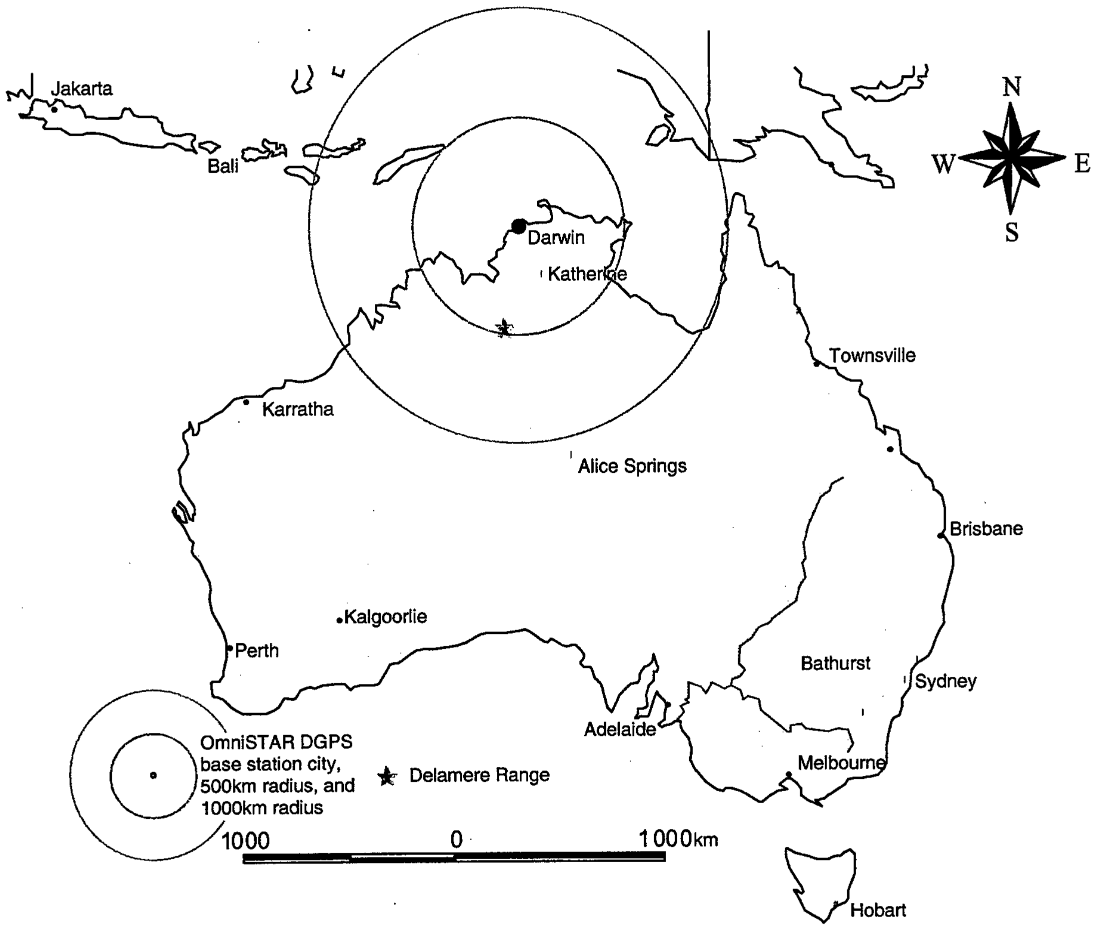

Figure 2 *The coverage of the differential correction service used by the AMRL GPS mapping system at Delamere range.*

3.2 Data collection

The system allows a user-defined library of features to be loading into the hand held data logger, which are usually referred to as Features or Themes. The details that are to be collected in the field (position, notes etc.), about each logged item are called Attributes. The data logger is connected to the GPS receiver, and is capable of logging about 2000 positions along with simple notes. Alternatively, a PC could be connected to the GPS and act as the data logger, although in this case a hand held data logger was used. The main short-comings of lap top computers in this context are their; poor screen visibility in sun light, large size and weight compared to a hand-held data logger and difficulty of entering data on a small key board. A pen-based computer with a screen designed for sunlight use would be more appropriate.

The library loaded into the data logger is known as the Data Dictionary. Typically, the Data Dictionary will include all the feature categories that are to be located and mapped. These are separated into point, line or area features. General (features not belonging to the other categories) point, line and area features are automatically included in the Data Dictionary to cover features not included in the rest of the Dictionary. These are listed as Point generic, Line generic and Area generic.

Data Dictionaries should be tailored to particular accidents, as the decisions made when choosing the features for inclusion in the Dictionary will affect the display and flexibility of the maps produced. While the data can be manipulated after the event, a good dictionary will save a lot of time in data manipulation during analysis.

The software used to control the data logger and generate the data dictionaries will also display the data as simple maps. To further manipulate the data and to join other data to the GPS and notes collected in the field, a more powerful software GIS package is used. All of the maps presented in this paper have been produced with the GIS package.

A Data Dictionary for this accident was prepared in the office prior to departure for the site using the Trimble Pathfinder Office software which comes with the Trimble GPS unit. It was subsequently modified prior to field use after discussions with the investigating team. The three 'General' Feature names were added without realising that the program would generate these automatically. This led to some confusion in the field and required some data manipulation. The Dictionary had the Features listed in Table 1. During data collection, the data is stored with a number of attributes for each position mapped. These included:

- GPS position time and date;
- height;
- position shape (point, line or area);
- correction type;
- feature name;
- data file;
- maximum pdop (a measure of error dictated by satellite geometry);
- number of fixes taken for this data point;
- standard deviation between fixes taken for a data point; and
- other user defined attributes.

Table 1. Data Dictionary used for the Investigation of the USMC F/A-18 Accident at Delamere Bombing Range NT, 20/8/1998.

Item classification (pre-site)	Feature type	User defied attribute collected	Actual feature name used (site)
Point Generic	Point		Point Generic
Line Generic	Line		Line Generic
Area Generic	Area		Area Generic
Fence	Line	Note	Fence
Road	Line		Road
Main Wing Right hand	Point	Note	Main Wing RH
Main Wing Left hand	Point	Note	Main Wing LH
Main Wing Parts	Point	Note	Main Wing Parts
Horizontal Stabilisers	Point	Left, Right	Hoz Tail
Vertical Stabilisers	Point	Left, Right	Vert Tail
Engine Main sections	Area	Note	Engine Main sections
Engine Parts	Point	Note	Engine Parts
Forward Fuselage	Area	Note	Forward Fuselage
Aft Fuselage	Area	Note	Aft Fuselage
Armament	Point	Note	Armament
Main Landing gear	Point	Note	Main U-C
Nose Landing gear	Point	Note	U-C front
Impact marks	Line	Note	Impact marks
Initial Impact point	Point		Initial Impact point
General Point	Point	General	General Point
General Line	Line	General	General Line
General Area	Area	General	General Area
Avionics	Point	Note	Avionics
Control surfaces	Point	Note	Control surfaces
Actuators	Point	Note	Actuators
Target	Point		Target
Range Tower	Point		Range Tower

Note: The software produces a separate attribute name for each attribute taken. So that the extra attributes added such as 'Note' and 'General' were not actually needed. The attributes that should have been added were a unique data point identifier such as 'item number' and the attribute 'photo number(s) to aid in correlating the photographs with the data points.

4. Field data collection and presentation

4.1 Introduction

AMRL sent two trained aircraft accident investigators with the GPS mapping equipment to Delamere. These officers arrived at Delamere on the evening of the 25th August and briefed the accident investigation team that night. A plan was formulated for the next day's events. It was decided that after a familiarisation of the site, the USMC investigator and an F/A-18 maintenance specialist should accompany the AMRL officers during the plotting of the wreckage. Although the AMRL officers intended to use the digital camera, which is part of the system, to document the wreckage, a RAAF photographer was on site to carry out this task. Consequently, the photographer also accompanied the plotting team. The majority of the team is shown in Figure 3. The AMRL digital camera was only used to take images of selected items thought to be of significant importance to the investigation.

Figure 3 *Ploting team - from the left – USMC F/A-18 maintenance specialist, RAAF photographer, AMRL officer with GPS equipment and USMC 'mishap' investigator. Photograph taken with digital camera by second AMRL officer.*

The following morning the mapping equipment was assembled, checked and trialed on the road outside the range facilities. This trial indicated that sufficient GPS satellites were in view and that the correction signal and equipment were working satisfactorily. A map of the road was produced on the portable computer using the GPS programming software and appeared to be an accurate representation of the road.

4.2 Mapping procedure

Prior to the arrival of the AMRL team, the USMC accident investigators had reconnoitred the site and marked those pieces of wreckage that were of interest to them. Most of this effort had been initially focused on finding and recovering the remains of the pilot. The positions from which these remains were recovered were marked with flags so that they could be mapped with the rest of the wreckage.

After initial equipment setup, the roads surrounding the site were mapped from a vehicle and the position on the front of the control tower was taken. These features were mapped to give reference indicators to the wreckage points.

Before beginning the wreckage mapping operation, the AMRL investigators walked around the site to gain a general feel for the extent of the wreckage spread. From this examination, it was concluded that virtually no wreckage lay to the south of the impact crater. (The aircraft had approached from this direction). The heading of the aircraft at impact appeared to be approximately 330° true, which in part was confirmed by the observers (from the night in question). This heading had been marked by pegs by the USMC team prior to AMRL arrival, and ran along the long axis of the impact crater.

Initial mapping consisted of tracing the extent of the impact crater, the dirt ejected from the crater and the position of the target. The general site layout is shown in Figure 4. This was

followed by mapping the positions of parts of interest immediately in and around the impact crater. Figure 5 gives an idea of the crater size and the nature of the surrounding range. The raked part of the range was devoid of trees and scrub. Beyond the raked boundary, the vegetation was mainly low trees with open grassed areas, shrubs and numerous termite mounds. Many practice bombs and other ordnance from previous missions were scattered thought the wooded areas close to the raked part of the range.

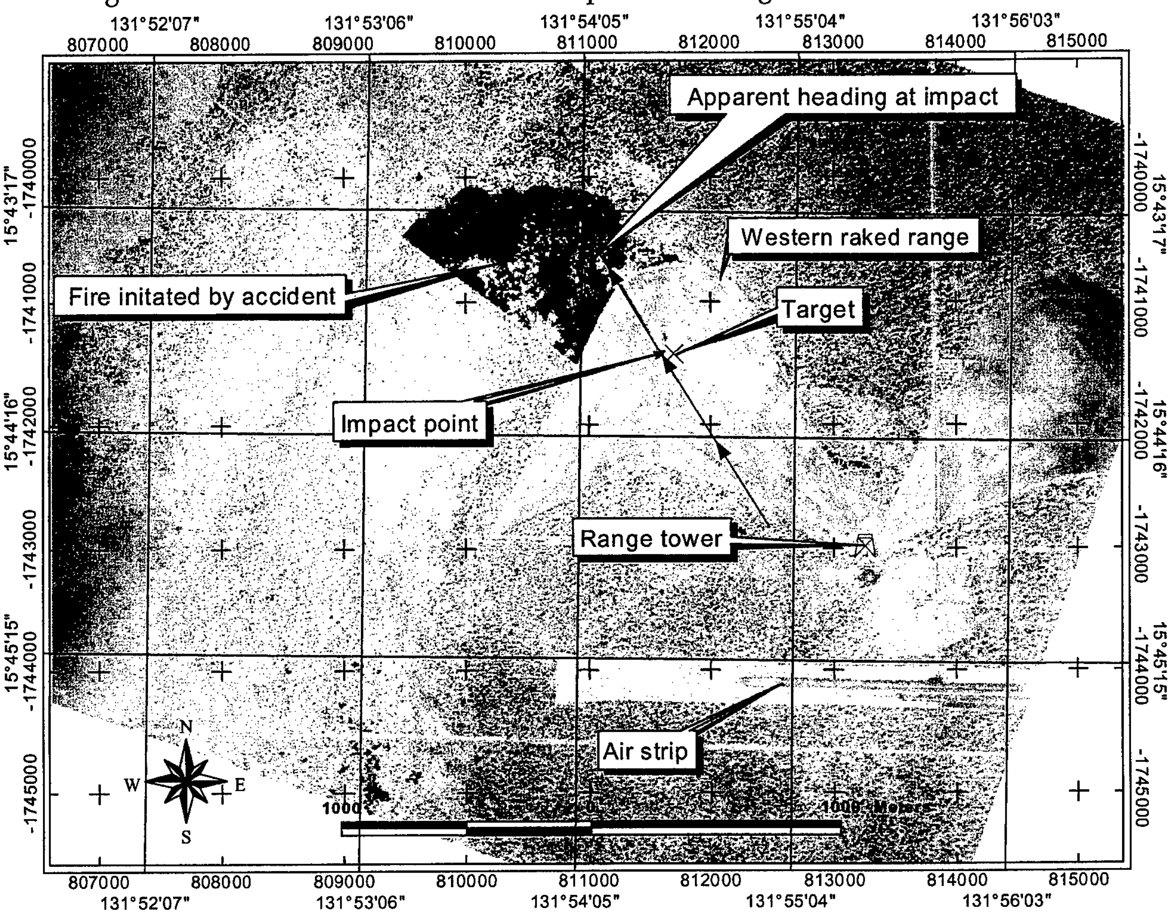

Figure 4. A map of the site shows the main points of interest.

Figure 5. The impact crater and the surrounding range. In the distance can be seen the edge of the raked range beyond which the indigenous vegetation existed (trees with an average height of 4m, and scrub) and anthills.

The mapping effort was separated into several regions and carried out in the order shown in Table 2. Figure 6, which also shows a larger scale aerial photo of the site, clearly defines the approximate boundaries of each mapping session. This map also shows the spread of the data collected. While a few parts were found outside these areas, they were not considered particularly important, consisting of small heavy low drag items or light wind-blown items.

Table 2 Schedule of work carried out at the accident site

Day	Session	Tasks carried out	Notes
Day 1		Travel to Delamere; initialise GPS and correction receiver. Brief accident investigation team and support staff. Review data dictionaries.	Most of the time was taken travelling to Delamere. Work complete at about 2000 hrs.
Day 2	Morning 0700 -1100hrs	Familiarisation walk around of the site. Mapping of crater and surrounding wreckage out to about 50m. Map western sector (270 to 300° true) out to boundary road	Mapping was ceased while laser designation from aircraft in the area occurred. The data collected was downloaded and a map created.
	Afternoon 1400 – 1800hrs	Map next sector (300 – 330° true) out to boundary road. Prepare map of days data. Brief team and support crew.	After each session, the map was updated. A review of the map gave confidence to begin the collection of the wreckage
Day 3	Morning 700 – 1200hrs	Map next sector (330 – 360° true).	The mapped wreckage parts were collected from this morning onwards.
	Afternoon 1300 – 1800hrs	Map next sector (0 – 30° true). Prepare map of days data. Brief team and support crew.	
Day 4	Morning 700 – 1900hrs	Map area beyond boundary road.	These parts were collected as the mapping proceeded.
	Afternoon 1300 – 1600hrs	Analyse maps and print. Discuss findings.	Collected parts were boxed ready for shipment

As can be seen from the table the majority of the work was completed in three days. This included mapping of about 500 parts, collection and sorting of the wreckage, and the production of a number of maps of the wreckage. Analysis of the site had reached an advanced stage by the end of this process because of the high quality information presented in the form of the maps produced.

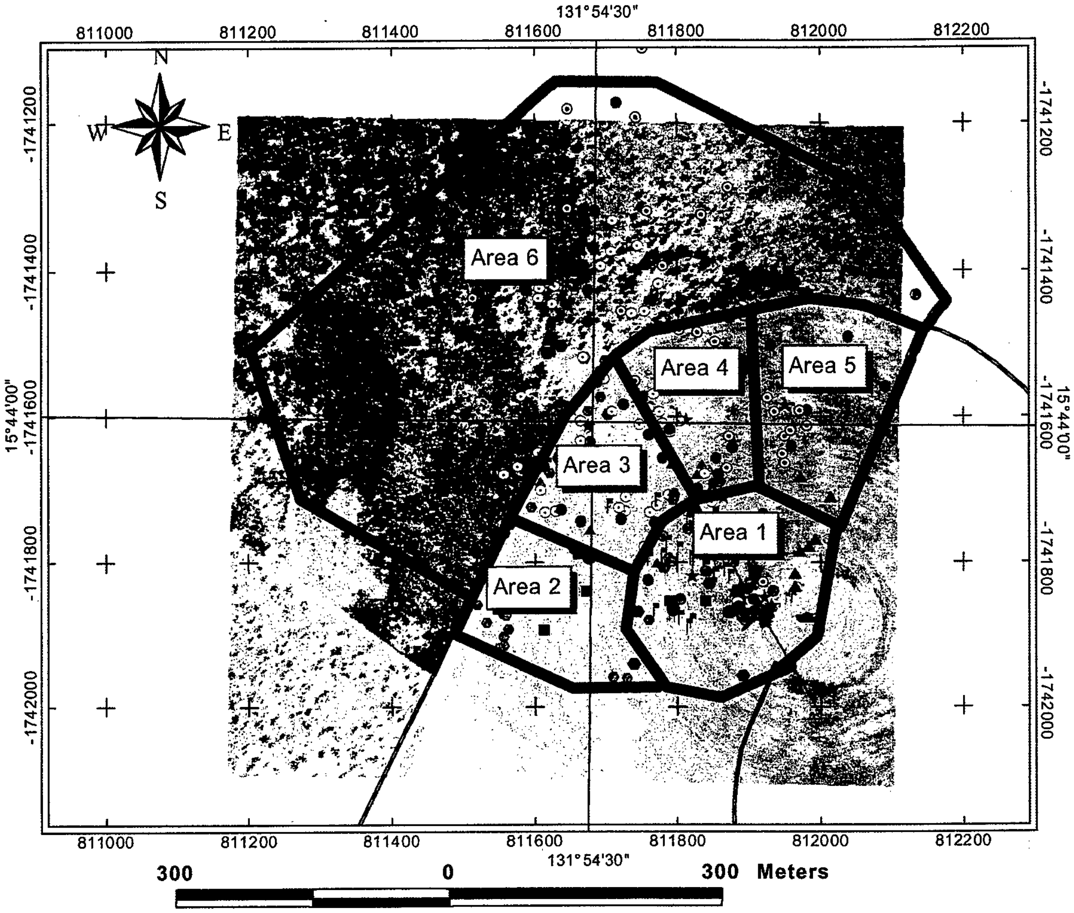

Figure 6 *The order in which areas of the wreckage site were mapped. This Figure also shows the data points gathered and other general features of the site. The aerial photo has been overlayed to give a feel for the terrain, which was very flat. Contours are not included because of the flat nature of the site.*

4.3 Results of the mapping

During the mapping of the wreckage, interim maps were produced and updated. Viewing these maps gave the investigating team the confidence to proceed with other tasks, therefore making far greater use of the available resources. The tasks included the collection of the mapped items and digging in the crater to search for further wreckage.

A map and legend of the wreckage site with all the mapped items shown, is presented in Figure 7. A list of the mapped items may be found in Appendix A. The map in Figure 7 indicates that the bulk of the wreckage was spread to the north west of the impact point, and that wreckage was spread over an area of about 600x600m (36 hectares). Some small heavy items were projected beyond these bounds. These were not considered significant enough to be mapped. A search back along the flight path did not find any debris that could have departed the aircraft prior to the impact.

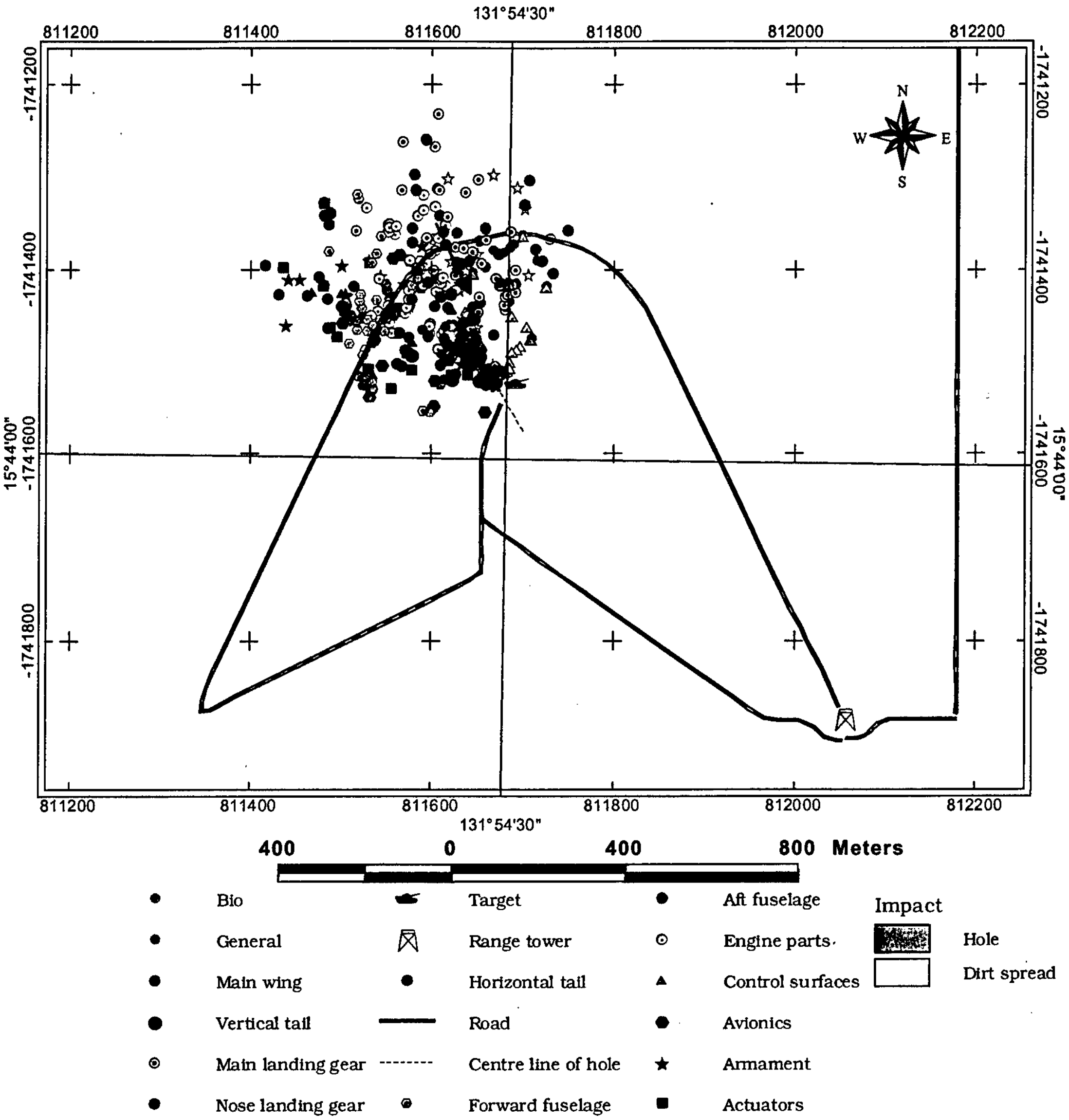

Figure 7 Basic map of the wreckage and the surrounding land marks.

A map of the impact crater is shown in Figure 8. The impact crater was elongated in the suspected direction of the aircraft's travel. The crater was about 17.8 metres long and about 7.9 m wide at its widest point. The widest point was about 10 m from the southern end of the hole. A wing tip launcher - LAU rail part was found embedded in the ground at the southern end of the crater. Other related parts were found nearby, along with a number of wing (side unknown) parts. The ground consists of a layer of compacted topsoil overlaying a local rock known as 'coffee rock'. This rock consisted of hard ball shaped stones embedded in a softer matrix. The crater was a little over 1.5 metres deep, and had penetrated into the coffee rock layer. Very little of the wreckage was present in this crater. After mapping the crater and surrounding material of interest, the crater was further excavated to reveal any buried wreckage. This excavation failed to uncover any further major wreckage items, indicating that the majority of the wreckage had been ejected from the hole during the impact.

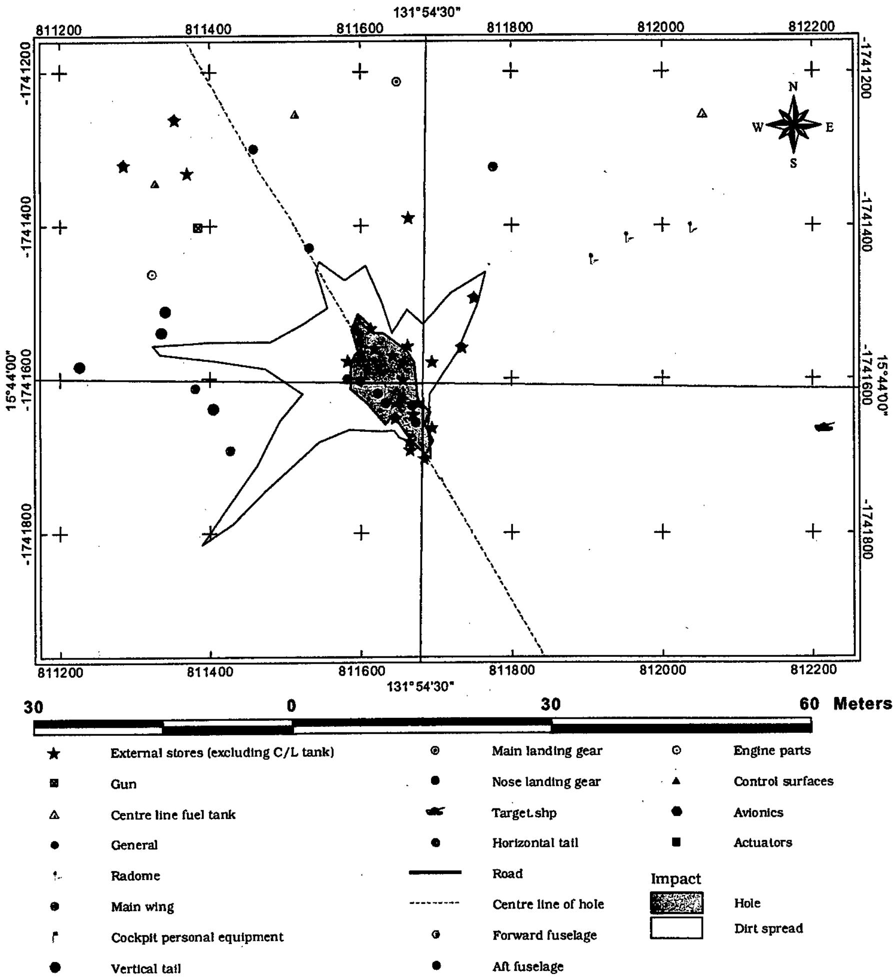

Figure 8 *Basic map of the impact crater showing the crater shape and the shape of the dirt thrown out by the impact*

The area surrounding the northern side of the crater was strewn with numerous small pieces of wreckage. Only selected pieces of this material were plotted. Several areas of burnt ground also existed in close proximity to the hole. These were not plotted.

A number of items were miss-identified at the start of data collection. The errors were mostly corrected on site. Other errors in the data occurred due to confusion over which of the data dictionary themes a particular item should be logged under. Many times an item could be classified under several of the theme names provided. In these cases, a theme thought to be most appropriate was selected in the field. On detailed review of the data, several of the items mapped were placed into new themes and other items were combined under existing themes. This has resulted in theme names which are, in some cases, slightly different to those used in the data dictionary (c/f. the data dictionary and the themes shown on the maps). After reviewing the original data dictionary, it was decided to formulate generic aircraft accident dictionaries for fixed wing and rotary wing aircraft (Appendix B). These will be used as a basis for future accident investigation requirements.

Each of the themes was plotted separately. These maps are shown, with their legends in Appendix C. Manipulations of these mapped data are shown and discussed in the Analysis section.

From the point of view of establishing the attitude, relative to the ground, of the aircraft at ground impact, several sources of information are usually used for F/A-18 aircraft accidents. These consist of: eye witnesses accounts, the MSDRS recorder, standby instruments, the crater size and shape, the wreckage spread and any information from fixed items, such as trees that might have been hit prior to ground impact.

As mentioned before, the witnesses, including the videotape evidence did not see/record the aircraft impacting the ground. None of the MSDRS, which contains a tape of the major aircraft parameters recorded during flight, and an IC memory chip that is a buffer for this instrument, could be identified. Only one part of one standby instrument was recovered. This was the ball from the standby Attitude Direction Indicator (ADI). Previous experience with this instrument has shown that a close inspection of the impact markings left on the ball can give the pitch angle (relative to the ground) of the aircraft at impact.

4.4 Examination of the Standby Attitude Indicator (ADI)

The ball and several parts of the Standby Attitude Indicator were found. The ADI parts were recovered and sent to the US for further examination. Prior to ADI recovery, the AMRL members were able to examine the ADI ball in the field. Previous experience by the AMRL investigators [10] with this instrument allowed the field observations to be used along with pictures taken at the time, to estimate the aircraft's pitch angle. (The roll angle was not decipherable from the cursory examination carried out in the field. The USN intended to further investigate this instrument).

Marks from the rear pitch drive gear and its drive shaft were evident on the ADI ball. The drive shaft had punched a hole in the ball on the 80° CLIMB bar. The drive shaft, which is aligned with the longitudinal axis of the instrument, normally sits in the centre of the drive gear. This means that the hole it created in the ball was diametrically opposite to the pitch reading on the front face of the instrument. Since the scale on the ball is non linear with respect to degrees of ball rotation and reads from 0-90° climb and 0-90° descend, while using 135° of the ball rotation for each (climb and descend), then a hole at the 90° mark on the back of the ball corresponds to a reading of 30° on the front of the ball. Therefore, the hole at 80° climb on the back of the ball suggests that the ADI reading at the time of impact was 40° aircraft centre-line to the ground. The cursory examination of the remains of this instrument did not give a roll angle.

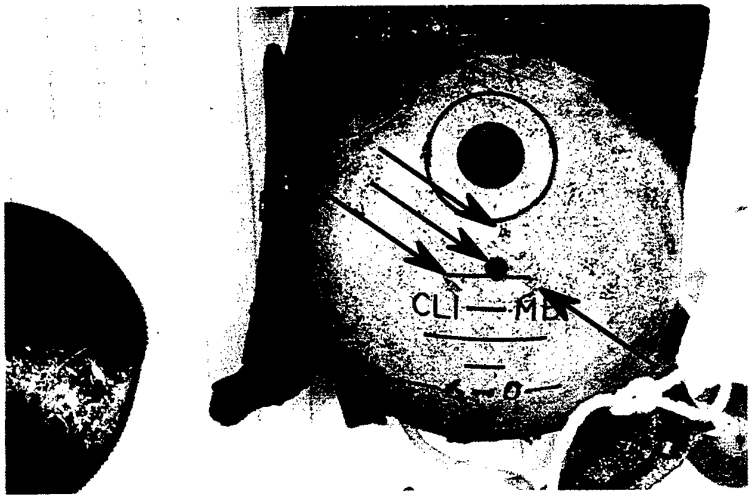

Figure 9 *The ADI ball found in the field showing the hole (red arrow) punctured by the drive shaft. The three black arrows indicate indentations caused by the three screw heads adjacent to the drive shaft.*

4.5 Centre-line Fuel Tank

Several sections of the centre-line fuel tank were also found. These were all located to the right of the impact crater. One section consisted of parts of the aluminium alloy casing. This section (Figure 10 A & B) of casing had been concentrically crushed along the longitudinal axis of the tank. This concentric crushing of the tank along its axis suggested that the main loading was applied to the leading tip of the tank, along the longitudinal axis of the tank.

A B

Figure 10 *A section of the centre-line fuel tank showing the concentric crushing of part of the aluminium casing.*

4.6 Other observations

An examination of numerous engine parts in the field found that most of the turbine blades were stripped, as expected if the engines were under power at impact. Most pieces of discs had rotational scoring and several other failures were consistent with engine rotation under power.

The extent of disruption and fragmentation of some of the more robust items such the engine discs suggested that the speed of the aircraft at impact was high.

One of the trailing edge flap actuators (found to the west of the crater centre-line) appeared to be in the neutral position suggesting no flap deflection.

No other AMRL investigations of the parts where undertaken, the parts were sent to the US for further examination. The results of these examinations were not made available to AMRL.

5. Analysis

5.1 Data processing

As mentioned earlier some processing of the data was carried out to improve the categorisation and presentation. Data are held in the GIS program as a series of tables. Each table is based on a theme. Rearranging the data involved merging tables and creating new tables. Other data can be added to these tables such as links to numerical data, labels, images and text files. The three main adjustments carried out in this exercise were:

(a) Some line and area data was converted to point data. To carry this out, the construction of a small routine was required. The conversion was necessary so that data, which had been logged either in the incorrect theme or in a theme that was only offered as a line or area theme, could be easily viewed on the maps.

(b) Data was corrected. Some items where mis-identified, such as parts of the centre-line fuel tank which were first thought to be parts of the nose radome (Note some of these parts have been plotted in the uncorrected state in Figure 8).

(c) Several types of data were collected from two or three files and formed into a single theme. For instance the biological data, cockpit seat parts, personal equipment and the publications (papers) were joined to form the 'cockpit personal equipment ' theme.

This processing of the data revealed several areas where the software could be improved for ease of use. These aspects are being followed up.

5.2 Linking Data

Hot-links from data points to the photographic images were created for several of the plotted items. This involved entering the file path name for the particular image into the data tables manually. This allowed viewing of the photos after clicking on an active data point on a view of the mapped data (an example of what a hot-linked image looks like on a map is shown in Figure 11).

The software procedure for linking is difficult to use and is somewhat limited in scope. Since this feature was not a requirement in this investigation (the photographs had mostly been captured by traditional means), no further effort was carried out to put all the photographic data into the database. In the future further development of the system will ease the linking of photographic data and allow linking of text data and possibly voice data with the maps. The aim is to make it easy to accomplish data fusion in the field.

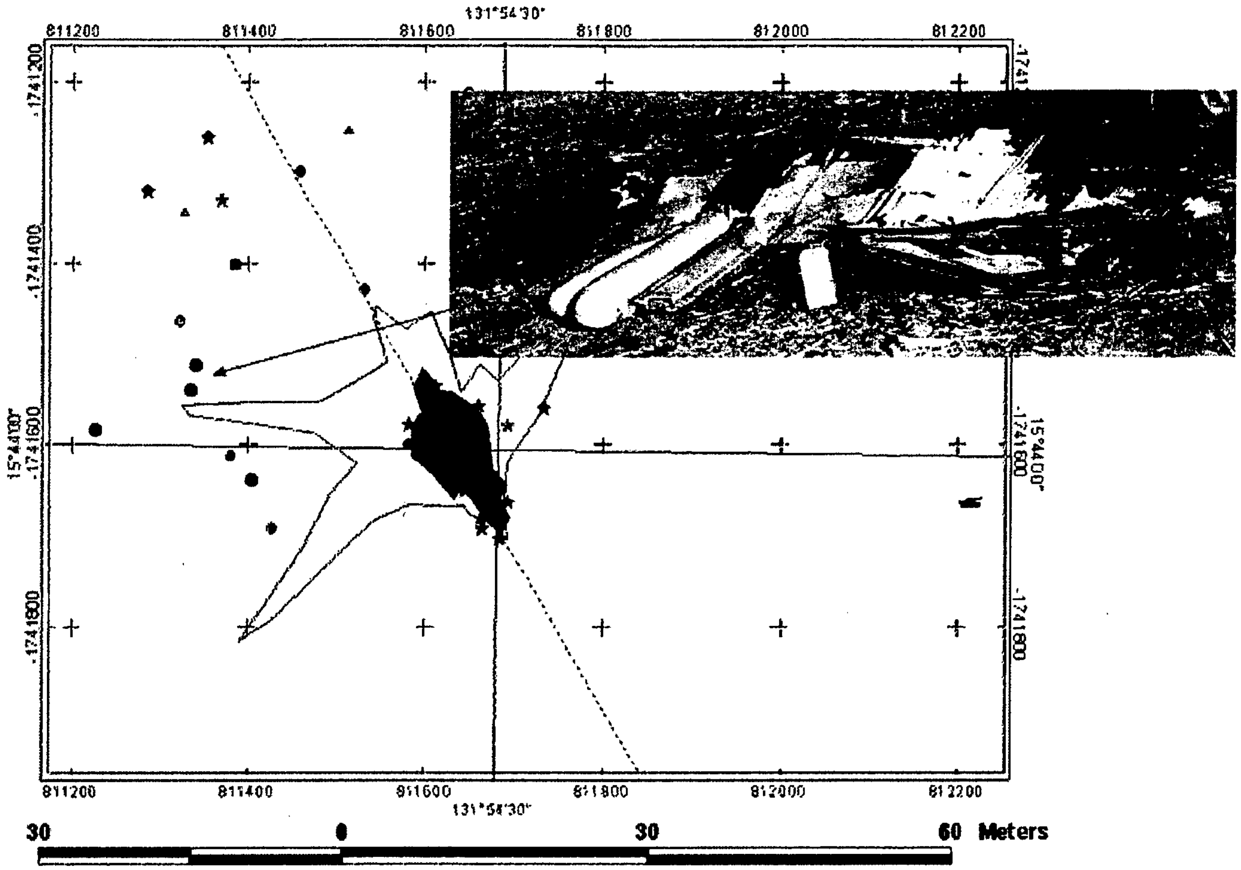

Figure 11 An example of a hot-linked picture file on a map.

5.3 Maps

The most notable feature of the wreckage distribution was an apparent grouping of similar items, from similar sections of the aircraft, in the wreckage field. An examination of wreckage items associated with the lower section of the aircraft, such as the main landing gear and the external stores (including the centre-line fuel tank), indicated that these parts were mostly to the north (right hand side) of the projected centre-line of the impact crater, Figure 12. Those parts that were associated with the upper part of the aircraft were to the west, Figure 13. This suggests that the aircraft was rolled to the left at impact. This fact is most notable if the underbody stores are compared to the position of the gun parts. The gun is in the upper part of the nose. The external stores and the gun are both heavy items and would be expected, if the aircraft were wings level, to travel in the direction of the aircraft's momentum. Figure 14 shows that this is not the case and it is clear that some other factor caused the underbody stores to deflect to the north while the gun parts deflected to the west. It is interesting to note that the position data for the external stores, centre-line fuel tank and gun parts were all collected under either the 'armament' or 'general' theme names. Without separating out this data, the pattern was not as strongly evident as is shown in Figure 14.

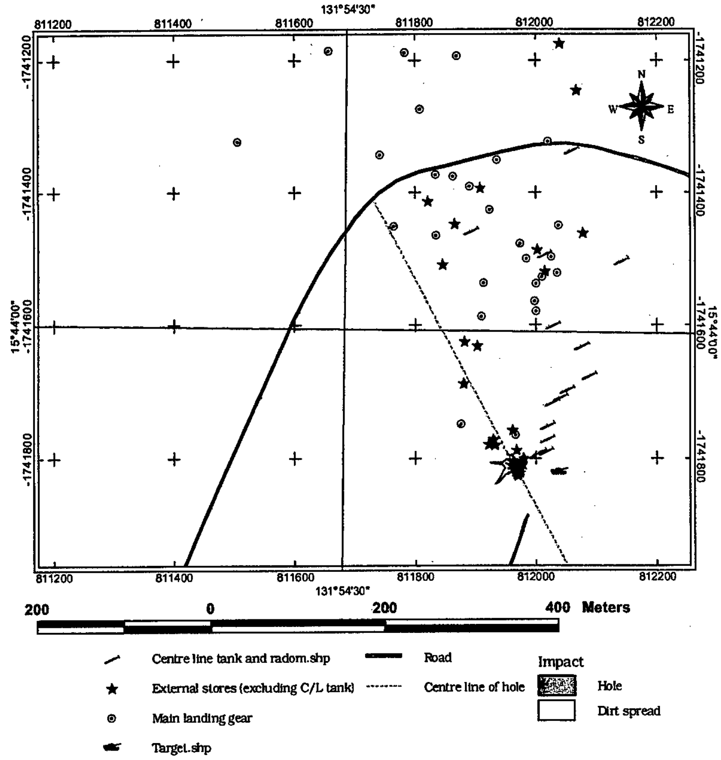

Figure 12 *The underbody stores, including the centre- line fuel tank and the main wheels were all deflected to the north of the expected direction of aircraft travel.*

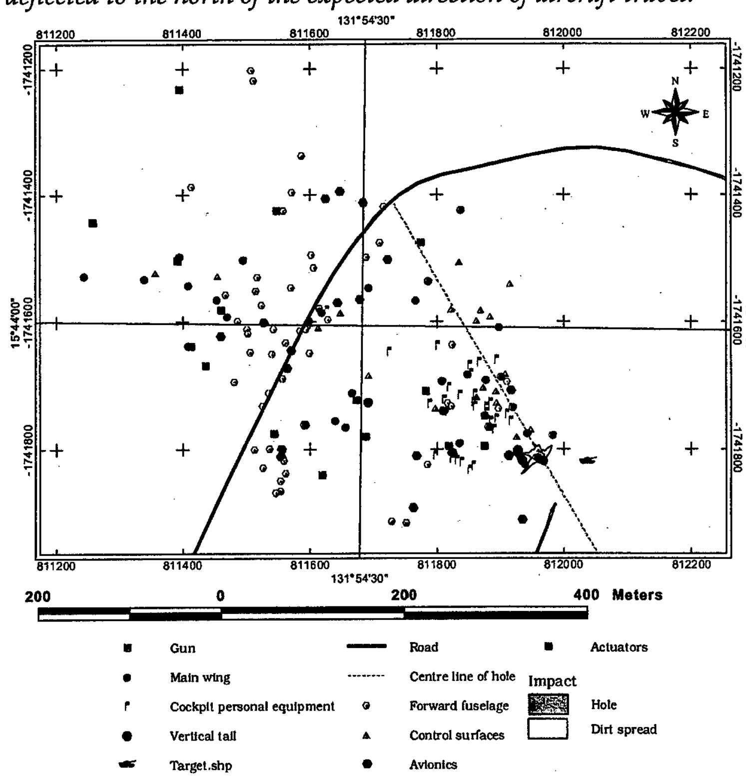

Figure 13 *The wings, forward fuselage, gun, cockpit items, actuators, avionics and tail parts were all deflected to the west of the expected direction of aircraft travel.*

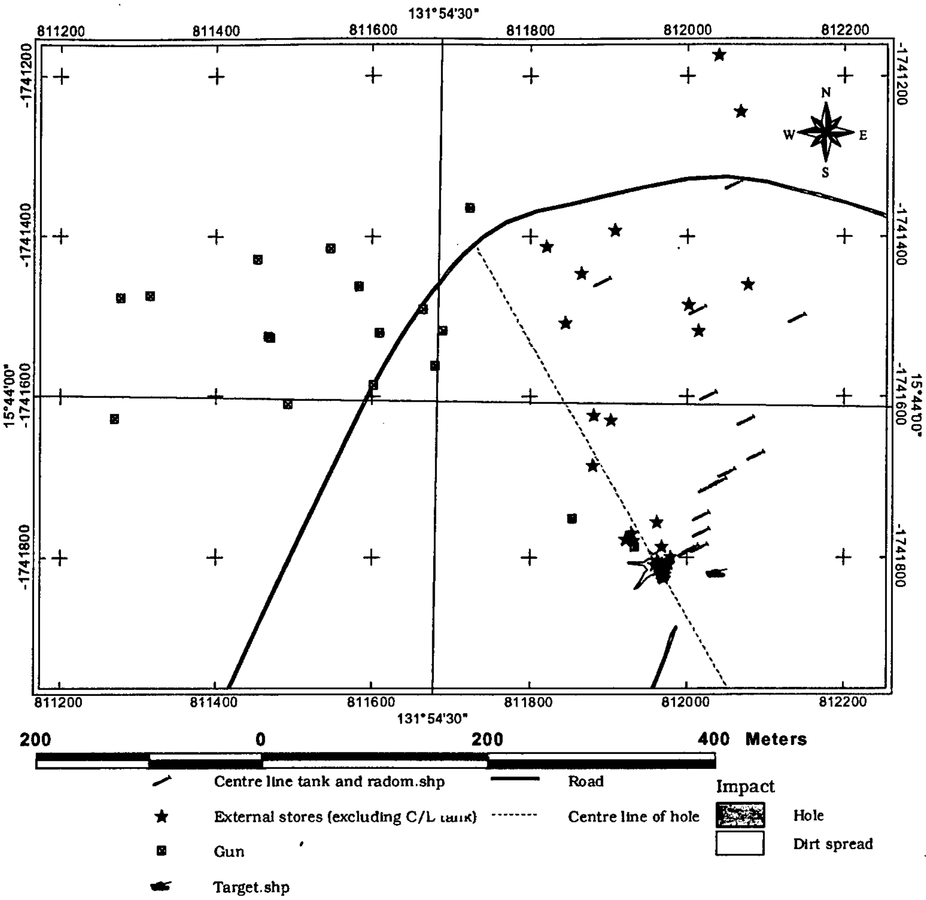

Figure 14 The gun, external stores and centre line tank showing the deflection of these heavy items to either side of the impact crater.

The cause of the deflection of items to either side is probably the result of two significant factors;

(a) The aircraft was banked to the left, and
(b) the engines, after impact travelled through the aircraft in approximately a straight line, deflecting items of the aircraft to either side.

Taking the second point first: An examination of the positions of the engine parts indicated that they had mostly travelled in the approximate line of aircraft travel, Figure 15. As would be expected the high mass of the engines, along with their aft placement would probably result in these parts having the least deflection from the aircraft's heading at impact. The very highly disrupted nature of the airframe in this accident also suggests that the engines travelled through the structure. The, relatively narrow width of the impact crater suggests a low angle of attack with wings vertical. These facts are supported by the observed nature of the crushing of the centre-line fuel tank, which appeared to have been crushed along its axis. Had an angle of attack been present the crushing of the centre-line tank would have been along an axis offset by the angle of attack.

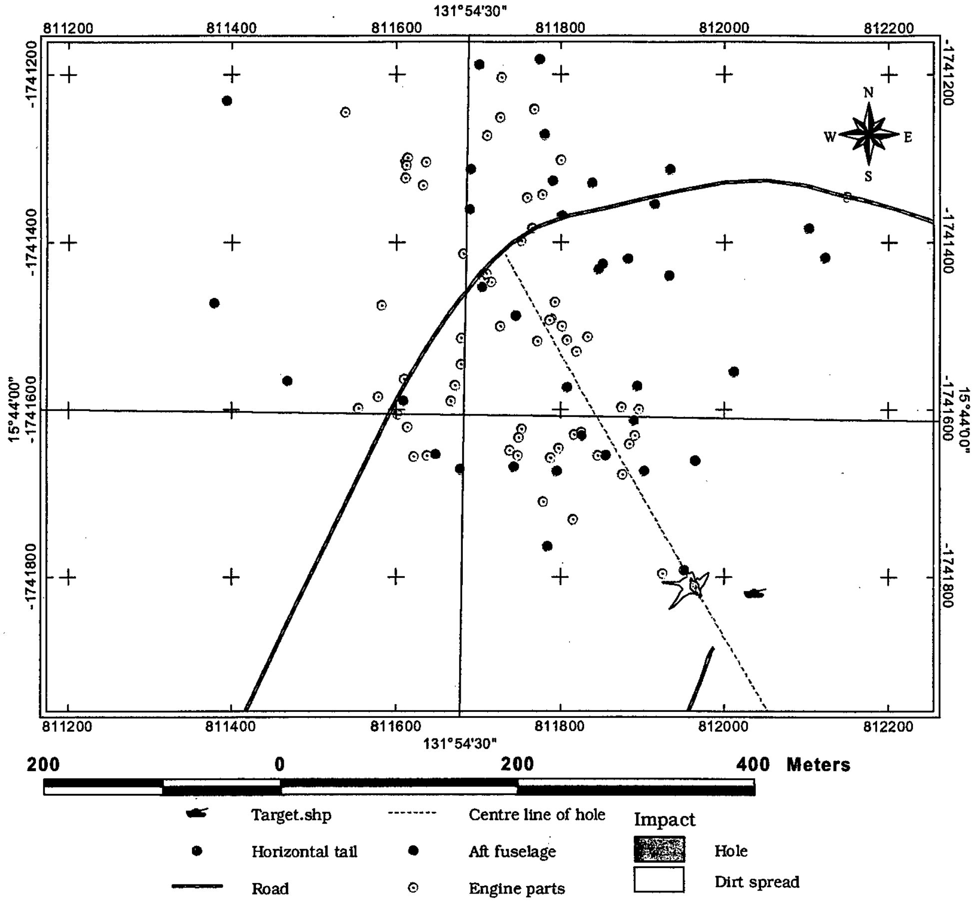

Figure 15 A map showing the engine parts, aft fuselage parts and the horizontal sabiliser parts. Note that all these parts appear to be clustered along the probable direction of aircraft travel at impact.

The evidence that supports the notion that the aircraft was banked to the left and entered the ground nose first is:

(a) Parts of a wing tip missile and launcher were found at the southern most end of the impact crater (the leading end of the crater) indicating that the end of one of the wing tips probably impacted at this point (see Figure 8).

(b) The projection of wreckage from specific areas of the aircraft to either side of the impact crater. Parts from below the aircraft were projected to the right of the aircraft's direction of travel and items from the upper part of the aircraft were projected to the left. This demarcation was so strong as to suggest that the aircraft was very steeply banked to the left.

(c) The long narrow impact crater, with no suggestion of wing shaped ground dents to either side. This suggests that the length of the hole is the projected wing span. For impact craters caused by aircraft with wings level at impact a wing silhouette is usually seen on the ground. The form of the dent is usually a projection of the shape of the wings on to the ground from the direction of travel. For example; if an aircraft flies straight into the ground (no yaw or angle of attack) the wing dent will be in the shape of the wing thickness and span - a long narrow dent either side of the impact crater. Whereas for an aircraft that hits the ground with an angle of attack, the cordwise length of the wing will be more evident in the shape of the wing impact dent and the length of the fuselage will be more evident in the shape of the crater. This will be further discussed in following sections.

(d) The evidence of the positions of the engine parts suggested that the major axis of the impact crater aligned well with the momentum vector of the aircraft. As the wing form impacts were well aligned (the length of the hole as discussed in the following sections) with this momentum vector, it is suggested that the aircraft had a bank angle of about 90 degrees.

(e) The observation that the vertical and horizontal tail surfaces were relatively intact suggests that they were the last items to impact the ground, after some of their forward energy had been dissipated.

A further examination of the items mapped in Figure 15 indicates that apart from the engines and aft fuselage parts travelling along the extended centre-line of the hole, indicating the axis of travel of the aircraft at impact, the horizontal tail also appears to be along this line. This would suggest that the tail was not generating either lift or down force at the time of impact. Either of these would have been expected to deflect the aerofoils to one or the other side of the direction of travel of the aircraft – remembering that the aircraft appears to be banked at about 90 degrees to the left. This also supports the notion that the aircraft was not pulling positive angle of attack at impact. This should be compared with the wings, which were probably generating some lift resulting in deflection to the west of the crater. The vertical tails would have been on its side to the left in this scenario, and therefore should be to the west side of the crater, as they were. The actuators were also spread to the west of the centre-line also, along with the control surfaces, as these are mostly associated with the wings. These features are shown in Figure 16.

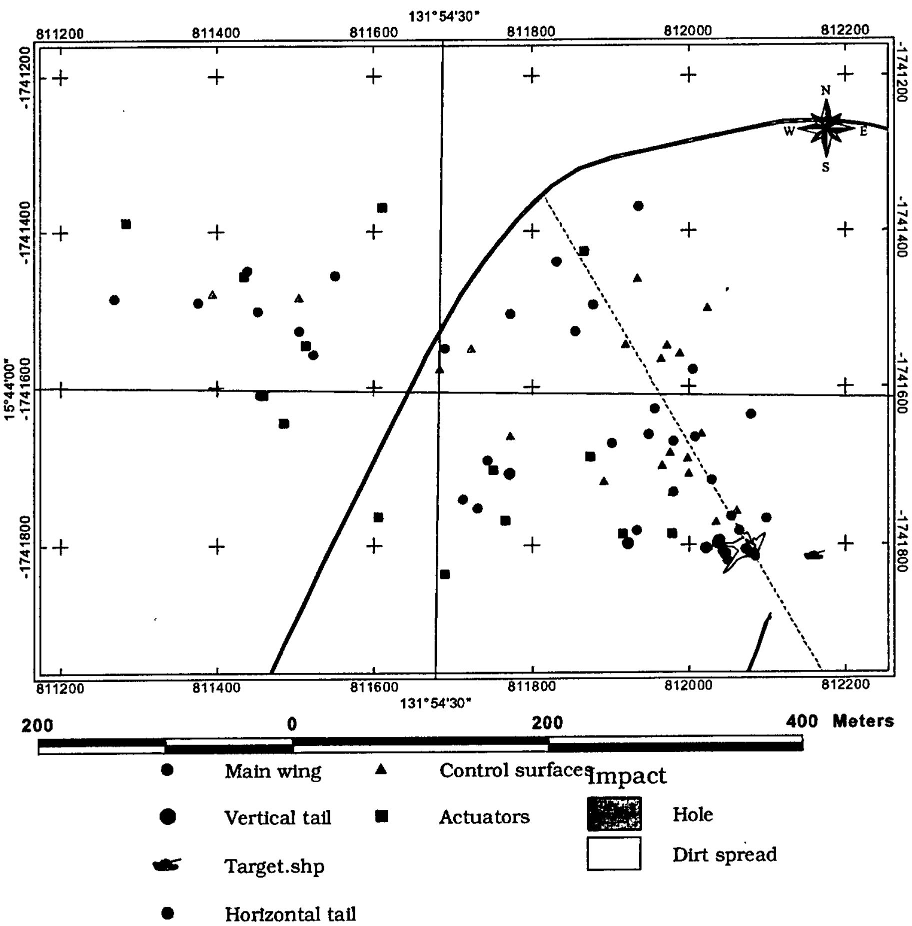

Figure 16 The positions of the lifting surfaces and associated parts indicating that the horizontal tail did not appear to be generating lift or down force at impact.

5.4 Impact hole

The spread of the wreckage suggested than the main momentum vector ie the direction in which the aircraft was travelling was roughly north west, and aligned with the centre-line of the impact crater. If the aircraft had impacted wings level the crater would have been of the form of a silhouette of the aircraft. Typically with wing impressions either side of the hole and an elongation of the hole depending on the angle of attack of the aircraft, the direction of travel of the aircraft and angle of the aircraft to the ground. Clearly the crater was not of this form. The analysis of the positions of certain wreckage items strongly indicated that the aircraft was steeply banked to the left at impact (probably about 900). The lack of wing impressions to the side supports this. With the aircraft banked by about 90 degrees to the left at impact, the length dimension of the hole takes on the wing form. If the width of the aircraft is considered along with the length of the hole, a calculation of the angle at which the aircraft struck the ground can be made. The geometry of this situation is shown in Figure 17. Knowing that the aircraft was 11.43m wide and the crater was about 17.8m long, and assuming that the entire length of the crater was caused as a result of the wing tip to wing tip dimension, the aircraft impact will be a reflection of the aircraft projected onto the ground from its direction of travel. Calculating this projection gives an angle that the aircraft would have made with the ground of about 40 degrees. This is supported by the evidence of aircraft attitude as suggested by the examination of the ADI.

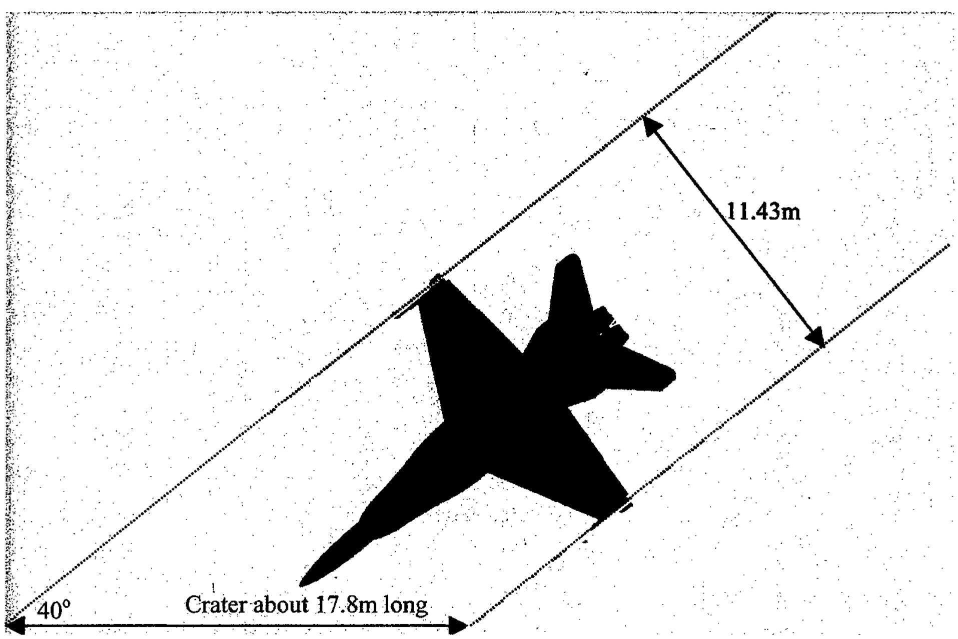

Figure 17. A projection of the aircraft onto the ground at about 40° gives the approximate length of the impact crater.

By using the map gained from the GPS data projected onto an image of the impact crater and surrounding area, it was possible to imagine the view that the pilot would have had just prior to impact. This view is from about 50m above the ground looking down the 40 degree to the ground line. Note that the target is outside this view. The view is shown in Figure 18. This imaging was prepared by using an image analysis program and a 3D program.

Figure 18 A view of the impact crater from about 50m above the raked range from roughly along the flight path of the aircraft. A projection of the map of the impact crater and dirt spread has been placed over the image of the crater.

By adding a 3D model of the F/A-18 aircraft to the image shown in Figure 18, and placing the model in the suspected orientation over the hole, it was possible to determine whether the hole was consistent with the hypothesis. It is also possible to try different angles of attack to seen if the projection of the aircraft is consistent with the impact crater. Three of these projections are shown in Figure 19. Although angles of attack from 0-10° appear to be possible, the ejecting debris could easily have widened the crater. This augment is not as strong when considering crater lengthening due to debris ejection. The main mass of the aircraft would have impacted the ground about the centre of the crater, resulting in widening to either side and towards the far wing tip. Since the impression made by the far wing tip is about 9m from the centre of the aircraft impact, there is considerable distance for crater lengthening without reaching the wing tip mark. Assuming perfect reflection, (ie. 40° in and 40° out of a 2m deep hole caused by a 2.5m (approx.) wide fuselage, then the widened part of the hole would be about 7.5m long). Naturally, the material exiting the crater would be wider, due to fuselage spreading, than the fuselage entering the hole and therefore the hole would be expected to be wider on the exit side. These points are consistent with the approximate length of the wide section of the crater, which is about 8.5m long, with the wider section of the hole being biased towards the furthest end.

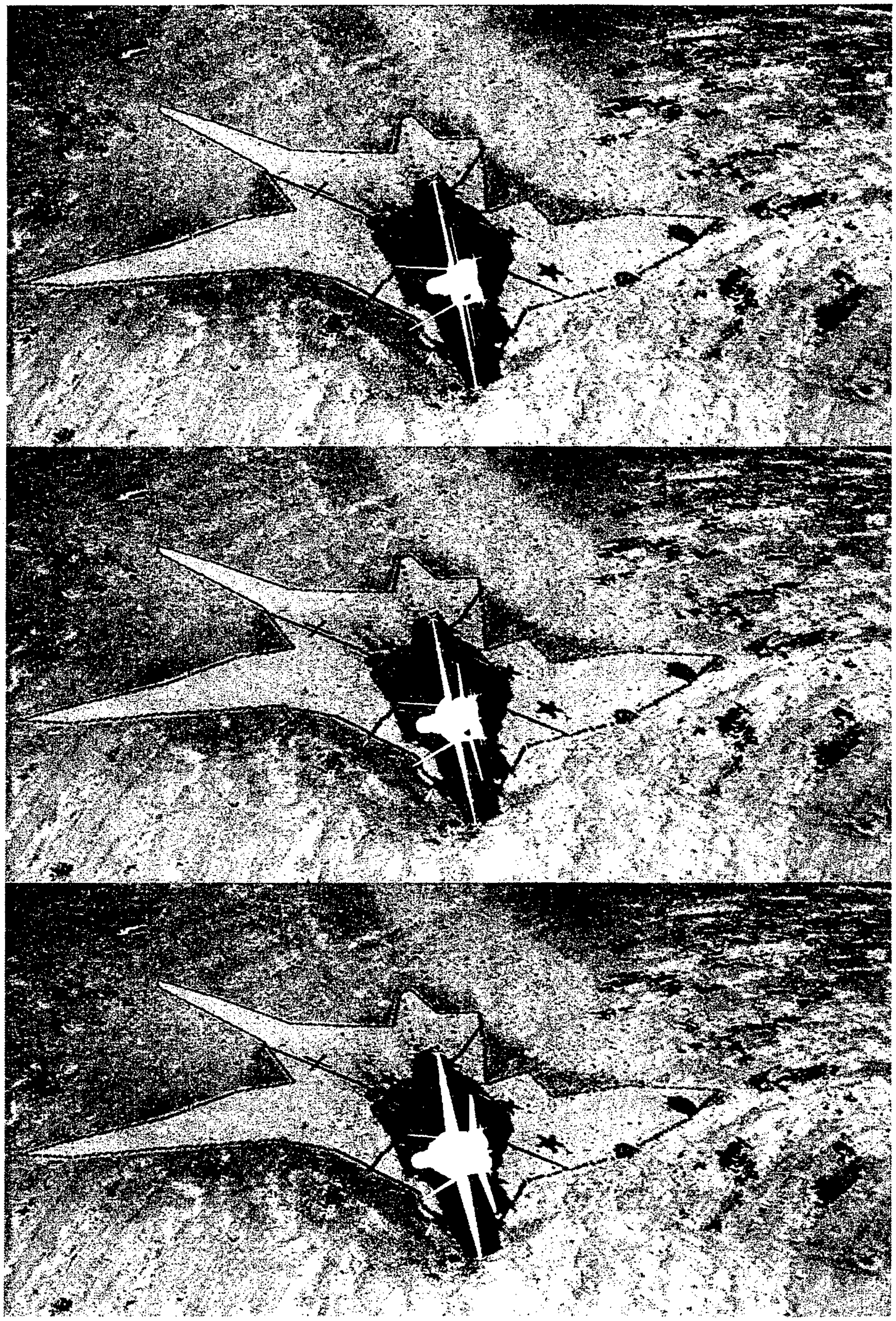

Figure 19 Three views of a projection of an F/A-18 on to the map and image of the impact hole. The first view is with the aircraft at a 0° angle of attack, the second at 5° angle of attack and the third at 10° angle of attack. Although all are possible the ejecting debris could easily have widened the crater.

5.5 ADI

Marks from the rear pitch drive gear and its drive shaft on the back of the ball suggested that the ADI reading at the time of impact was 40° aircraft centre-line angle to the ground. The impact crater hole length and the notion that the aircraft was rolled about 90o to the left at impact support this evidence

5.6 Pilot control inputs

The evidence suggests that the aircraft was banked to the left by about 90° and that there was little or no angle of attack at impact. There appeared to be no significant deflection of the horizontal stabilisers. The engines appeared to be at high rpm and one of the trailing edge flap actuators appeared to be in the neutral position. All of these observations suggest that the pilot had not input any significant control changes in an effort to avoid the impact.

6. Conclusions

The trial of the GPS wreckage mapping system at the accident site of a United States Marine Corps F/A-18 aircraft, which crashed at Delamere bombing range in the Northern Territory, was a success. The maps generated on site were of great assistance to the analysis of the accident. The speed with which the information was made available to the investigators was also a considerable advantage over conventional surveying methods and allowed considerable savings in time and effort.

Since these data were ideal for the further development of the system, the data were further manipulated to produce informative maps of the wreckage. These maps were used to allow AMRL to form its own opinion of the flight path of the accident aircraft just prior to impact. Other software was also trialed during this exercise. This software added to the visualisation capabilities of the AMRL system and will be incorporated into the system along with several system modifications designed to ease data collections and manipulation.

6.1 Conclusions about the accident

The main findings of the analysis of the data collected by AMRL along with some wreckage evidence are as follows:

(a) The United States Marine Corps F/A-18 impacted the ground with a bank angle of about 90° left wing down.

(b) The aircraft impacted the ground at about 40° to the ground with little or no angle of attack.

(c) The wreckage was mostly ejected from the hole at about the same angle as it entered ie. 'reflected'.

(d) There was no evidence that suggested that the pilot had input any control commands that would have indicated that he had observed the impending impact.

6.2 Conclusions bout the GPS system and GIS software

The main findings from the further investigation of the GPS system, GIS and the 3D software were:

(a) The GPS system performed satisfactorily on site at Delamere.
(b) The GIS software will allow extensive data manipulation and will allow the inclusion, or linking to, of numerous other sources of data.
(c) Several aspects of this software are needlessly complicated or are not particularly focused on allowing ease of use – these areas will need to be altered, which is possible using the softwares own programming shell.
(d) The 3D software is at present capable is displaying images which will considerably enhance visualisation of aircraft accidents and the events leading up to them.
(e) The 3D software is at present difficult to learn although simple model manipulation is reasonably easy.

6.3 Further development

The field trial of the GPS system and the analysis of the data with the GIS package have shown several areas where further development can take place:

- The field system requires a method of taking positions in areas where the satellites are masked. This has been addressed by the addition of laser range finder, inclinometer and compass modules. These devises pass their offset information directly to the data logger which offsets the current GPS position of the masked item.

- The GPS equipment and containers are over the 32kg limit for air transport by domestic airlines. The construction of lighter transport cases and lightening of some of the equipment will address this.

- The field collection software is somewhat limited in its manipulation abilities. Other software, which will drive the GPS and peripherals, is being investigated. Upgrades may need to be purchased

- The GIS software has several shortcomings that will need to be addressed to make data manipulation and presentation easier. The basic software gives an excellent basis upon which to increase analysis power. This will probably require some routines to be written by the Australian representatives of the software company and other software modules to be purchased.

- The 3D software is at present difficult to learn; other packages will be investigated.

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Appendix A: Delamere USMC Hornet Incident – Wreckage Recovery and Plotting BUNO 163743

GPS No.	Photo No	Component (Probable)	Comment
	Roll 1-4		Used prior to arrival
1.	Roll 5 - 1	LAU-7	
2.	-2	LAU-7 Nitrogen Bottle	Burst
3.	-3	MER Ejector Jack	
4.	-4	MER Stabiliser Foot	
5.	-5	Laser FLIR	
6.	-6	LGTR (Laser Guided Training Round)	On LH wing
7.	-7	Centre MER + BRU	
8.	-8	MER (AFT)	
9.	-9	~~Mk76~~	Found to be an Aust BDU 33
10.	-10/11	Pylon	
11.	-12	Aft end of AIM9	
12.	-13	Wing attach lug	
13.	-14	Wing fold transmission	
14.	-15	Inboard LEF actuator	
15.	-16	Wing root lap joint splice	
16.	-17	Outboard LEF actuator	
17.	-18	Wing spar	
18.	-19	AIM9 front fin	
19.	-20	LAU-7 Aft Fairing	
20.	-21	Wing Conduit	
21.	-22	VT strobe	
22.	-23	Pylon attach point	
23.	-24	Left VT	
24.	5-25	Rudder attach points	
25.	5-26	Left Aileron Actuator	
26.	5-27	~~Mk 76~~	Found to be an Aust BDU 33
27.	5-28	~~Mk 76~~	Found to be an Aust BDU 33
28.	5-29	TEF	
29.	5-30	HSTAB Tip	
30.	5-31	AIM9 seeker (Fwd end) + BRU32 piece close by	
31.	5-32	AIM9 mid section	
32. *	5-33	T FLIR (fire)	
33. *	5-34	~~Radome~~ Centre Line tank	Not crumpled but flattened
34. *	5-35	~~Radome~~ Centre Line tank	
35. *	5-36	~~Radome~~ Centre Line tank	no tag
36.	6-1	Mk 76	Excavated and put back
37.	6-2	Radar? (burnt carbon and alum around)	
38.	6-3	Flight Gear	
39.	6-4	Flight Gear	
40.	6-5	parachute	
41.	6-6	Parachute cord	
42.	6-7	Flight Gear	
43.	6-8	HSTAB attach piece	
44.	6-9	Flight Gear (Harness)	
45.	6-10	Wire Harness	
46.	6-11/12	LEX Fence	Only score marks
47.	6-13	Wire bundle (wave guide)	
48.	6-14	LEX aft section	
49. *	6-15	Fuel cell access panel	
50.	6-19	Canopy structure	
51.	6-20	Canopy Seat component	
52.	6-21	Aft windscreen mount (LH side)	
53.	6-22	Canopy Structure	
54.	6-23	HSTAB actuator component	
55.	6-24	Fuel cell access panel	
56.	6-25	Canon plugs (2)	
57.	6-26	Avionics (unknown)	
58.	6-27	Seat rocket motor	expended
59.	6-28	Fuel Cell valve	
60.	6-29	Wing attach bulkhead upper lug	
61.	6-30	Cockpit plugs	
62.	6-31	LEF Servo	
63.	6-32	Fuel cell access panel	
64.	6-33	Wire bundle	
65.	6-34	Wing attach bulkhead	
66.	6-35	LEX panel	
67.	6-36	Speed brake mount	
68.	7-1	Actuator piece	
69.	7-2	RH vertical stabiliser	
70.	7-3	Wing attachment Lower	
71.	7-4	Speed brake	
72.	7-5	Fuel cell access panel	
73.	7-6	Rudder Surface	
74.	7-7	Part of G-suit	
75.	7-8	Avionics (multi-bus)	
76.	7-9	Gun blast deflector	
77.	7-10	PPC	
78.	7-11/12/ 13/14	Attitude Indicator & Black panel & HUD tape	
79.	7-15	Wing attach bulkhead	
80.	7-16	Centre wing fold conduit	
81.	7-17	Guide vanes	
82.	7-18	A5 BIO	
83.	7-19	TEF shroud (RH?)	
84.	7-20	A1 BIO	
85.	7-21	Horizontal stabiliser Arm (LH)	No. C1-04
86.	7-22	Compressor disc (broken)	
87.	7-23	Inboard wing section piece	
88.	7-24	Compressor disc	
89.	7-25	LH horizontal stabiliser horn	
90.	7-26/27	Engine Casing	
91.	7-28	Pubs	
92.	7-29	Speed brake mount	
93.	7-30	Aft Engine Mount	
94.	7-31	RH TEF/Fuselage fairing	
95.	7-32	Fwd engine mount	
96.	7-33	Compressor Disc	
97.	7-34	~~Seat Rocket Motor~~ Canopy Thruster	expended
98.	7-35	Compressor disc with bearings	
99.	7-36	Inboard TEF Hinge	
100.	8-2	Engine spray bar assembly/piece of dorsal deck longeron	
101.	8-4	Canopy deck	

102.	8-5	Wing root splice	
103.		Pubs	No tag
104.	8-19	Unknown Avionics	No tag
105.	8-6	Upper Engine Mount	
106.	8-7	Rudder lower hinge	
107.	8-8	Canopy frame piece	
108.	8-9	Canopy Aft lock	
109.	8-10	Canopy structure	
110.	8-11	Seat part	
111.	8-12	Circuit breaker pieces (Relay)	
112.	8-13	Cockpit gauge	
113.	8-14	Piece of pitot/static line	
114.	8-15	Seat part	
115.	8-16	Fwd bulkhead mouldline	
116.	8 ?	VT attach STAB	
117.	8-20	Main engine shaft	
118.	8-21	IFR probe (fuelling probe) part	
119.	8-22	Stator VSV casing	
120.	8-23	Wing lug	
121.	8-24	Mid barrel gun piece and gearing	
122.	8-25	Compressor Disc	
123.	8-26	Gun gearing	
124.	8-27	Gun barrel fwd portion	
125.	8-28	Aft canopy mount	
126 @	8-29	LEX fence	
127.	8-30	Avionics Unknown	
128.	8-31	Compressor disc	
129.	8-32	RH HSTAB	
130.	8-33	Compressor piece	
131.	8-34/35	Compressor piece	
132.	8-36	Combustor	
133.	9-1	AMAD hydraulic port	
134.	9-3	Radome Hinge	
135.	9-4	Main Wheel	
136.	9-5	Hydraulic switching valve	
137.	9-6	Engine Hot end component	
138.	9-7	After burner casing	
139.	9-8	LH LEX light	
140.	9-9	RH inner wing	
141.	9-10	Tail hook actuator mount	
142.	9-11	LEF transmission	
143.	9-12	Turbine disc	
144.	9-13	Compressor disk piece	
145.	9-14	Compressor disk	
146.	9-15	Tail hook end	
147.	9-16	Turbine disc	
148.	9-17	Fire Botte/compressor disc	
149.	9-18	Turbine wheel	
150.	9-19	AMAD mount	
151.	9-20	Compressor case	
152.	9-21	Seat safing lever	
153.	9-22	HSTAB trailing edge	
154.		A9 BIO	
155.		A7/A8 BIO	
156.	9-23	LH Wing tip	Aileron embedded
157.		A6 BIO	
158.	9-24	LAU-7	
159.	9-25	Pylon piece	
160.	9-26	Gun timing gear	
161.	9-27	Compressor disk piece	
162.	9-28	Flight gear (D9)	No tag
163.	9-29	Flight gear (D10) pen holder	No tag
164.	9-30	Flight gear	No tag
165.	9-31	Flight gear	No tag
166.	9-32	Flight gear	No tag
167.	9-33	Flight gear	No tag
168.	9-34	Flight gear	
169.	9-35	Aileron part	
170.	9-36	Aileron shroud part	
171.	10-2	IFR fuel probe	
172.	10-3	Rudder piece/Wing tip piece	
173.	10-3	MLG Retract actuator	retracted
174.	10-4	Personal gear (Flight bag-tag)	No tag
175.	10-5	Personal gear	No tag
176.	10-6	Pubs	No tag
177.	10-7	Outboard TEF Hinge	
178.	10-8	Outboard aileron section	
179.	10-9	BRU-32 ejector	
180.	10-10	RH Wing tip	
181.	10-11	Oil retainer engine turbine drive shaft	
182.	10-12	Personal harness	
183.	10-13	Personal gear harness	
184.	10-14	Hydraulic reservoir	
185.	10-15	Centre tank part	
186.	10-16	Centre tank part	
187.	10-17	Centre tank part	
188.	10-18	Centre tank part	
189.	10-19/20	Centre line tank former	
190.		Centre line tank former	No tag
191.	10-21	WR part	
192.	10-22/23	Main UC door (D3)	
193.	10-24 @	Inboard aileron	
194.	10-25	MER (3 pieces)	
195.	10-26	Outboard inner wing (LH ?)	
196.	10-27	Radar component?	
197.	10-28	RH door 64	
198.	10-29	HSTAB (sooty)	
199.	10-30	LAU-7 (piece)	
200.	10-31	Compressor casing part	
201.	10-32	Pylon aft end	
202.	10-33	Door 68 (engine bay)	
203.	10-34	RH wing panel	
204.	10-35	Shoe boot heel	Placed in BIO box
205.	10-36	Wing attachment lug	
206.	11-2	Rudder lower hinge	
207.	11-3	Outboard LEF transmission	
208.	11-4	Fwd ground refuel panel	
209.	11-5	Outboard TEF roller	

210.	11-6	Nose wheel	
211.	11-6	Compressor blade	
212.	11-7	TEF	
213.	11-8	Compressor blade	
214.	11-9/10	RH aileron	
215.	11-11	Aileron inboard hinge	
216.	11-12	Main tail hook shank	
217.	11-13	Main U/C tire	
218.	11-14/15	Nose U/C axel	CPT 4088WH
219.	11-16	LEF gearing	
220.	11-17	Main wheel rim piece	
221.	11-18	Centre line tank mounting	
222.	11-19	Pylon piece	
223.	11-20	TEF hinge	(AMRL would like)
224.	11-21	Compressor wheel	
225.	11-22	Forward end of compressor	
226.	11-23	Nose wheel hub	
227.	11-24	Bleed air pressure valve	
228.	11-25	Aft end of compressor	
229.	11-25	Variable VEN actuator	
230.	11-`26	Turbine inlet section	
231.	11-27	Compressor disc hub	
232.	11-28	Main U/C strut (LH)	
233.	11-29	Flow meter (?)	
234.	11-30	Pylon part	
235.	11-31	APU impellor	
236.	11-32/33	APU turbine	
237.	11-34	APU piece	
238.	11-35	RH wing fold transmission	
239.	11-36	BRU-33	
240.	12-2	Main U/C up lock	
241.	12-3	Main U/C up lock hook	
242.	12-4	APU Impellor (?)	
243.	12-5	Fuel control valve	
244.	12-6	Engine parts	
245.	12-7	Engine ejectors	
246.	12-8	HSTAB actuator	
247.		Boundary marker	No tag
248.	12-9	Centre line tank aft cone	
249.	12-10	Main U/C tire and AMAD piece	
250.	12-11	Main U/C trunnion piece	
251.	12-12	Piece of AMAD	
252.	12-13	Main U/C Upper trunnion	
253.	12-14	Main U/C Side Brace	
254.	12-15	Piece of centre line pylon	
255.	12-16	Brake housing	
256.	12-17	Nose U/C attachment pin	
257.	12-18	Main U/C side brace attachment brace	
258.	12-19	Centre line tank aft pivot	
259.	12-20	Piece of MER	
260.	12-21	Main U/C shock absorber and down lock actuator	
261.	12-22	~~Unknown structure~~	RH LAU-116 centre section
262.	12-23	Main U/C connecting link	
263.	12-24	Intake mould line	
264.	12-25	Main U/C axel lever	
265.	12-26/27	Main U/C wheel hub	SN 2177
266.	12-28	BRU-32 ejector	
267.	12-29	Airflow motor	
268.	12-30	Fuel valve	
269.	-		
270.	12-31	Heat exchanger	
271.	12-32	Nose U/C drag brace piston	
272.	12-33	MER piece	
273.	12-34	Main U/C attach trunnion	
274.	12-35	Spring	
275.	12-36	Centre line tank attachment lug	
276.	13-2	MLG inner trunnion	
277.	13-3	MLG side brace down lock	
278.	13-4	Intake former piece – bulkhead	
279.	13-5	Engine oil part	
280.	13-6	Environ. System control valve	
281.	13-7	Bulkhead pieces	
282.		Crater rock (?)	No tag
283.	13-8	Nose U/C jacking point	
284.	13-9	Centre pylon piece	
285.	13-13	Nose U/C retract actuator	
286.	13-10/11/12	Hip Bone	No Tag
	13-14/15/ 16/17/18/1 9	Matrix Library	
287.	13-20	Actuator Rod and casing (TEF?)	Dated 29 Aug 1998
288.	13-21	(Fwd ?) Bulkhead piece	
289.	13-22/23	Avionics	
290.	13-24	Inner wing piece + TEF actuator servo	
291.	13-25	Canopy lock	
292.	13-26	C02 cartridge (seat)	
293.	13-27	Bleed air leak detector	
294.	13-28	Seat end cap (with powder)	
295.	13-29	Fwd Fuselage piece	
296.	13-30	Fwd fuselage bulkhead	
297.	13-31	Fwd fuselage bulkhead	
298.	13-32	Circuit breaker panel	
299.	13-33	Canopy thruster bracket	
300.	13-34	Wing attachment bulkhead lug region	
301.	13-35	Wing attachment bulkhead lug region	
302.	13-36	Hydraulic reservoir	
303.	14-2	WR attachment lug	
304.	14-3	Actuator piece	
305.	14-4	LEF Torque tube	
306.	14-5	Fwd fuselage piece	
307.	14-6	Aft section gun barrel	
308.	14-7	Gun back plate	
309.	14-8	Speed brake actuator	
310.	14-9	Wing attach bulkhead section	
311.	14-10	Seat part	
312.	14-11	Seat emergency oxygen bottle	
313.	14-12	Inlet guide vane	

314.	14-13	Aft top engine mount	
315.	14-14	Piece of gun housing	
316.	14-15	Fwd engine mount	
317.	14-16	Piece of gun casing	
318.	14-17	Fuel probe (IFR aft end)	
319.	14-18	IFR probe piece	
320.	14-19	Engine part (actuator)	
321.	14-20	Gun barrel	
322.	14-21	HSTAB servo	133° true back to aircraft. 409metres.
323.	14-22	Gun barrel	
324.	14-23	Control stick yoke	
325.	14-24	Aft LEX mount	
326.	14-25	Unknown avionics	
327.	14-26	Unknown avionics	
328.	14-27	Unknown avionics	
329.	14-28	Compressor piece	
330.	14-29	Compressor disc piece	
331.	14-30	Fwd engine bearing	
332.	14-31	Compressor disks	
333.	14-32	Main engine shaft	
334.	14-33	Fwd Engine mount	
335.	14-34	Engine piece	
336.	14-35	Fwd bulkhead	
337.	14-36	Gun gearing	
338.	15-2	HSTAB spindle	
339.	15-3	Fuel transfer pump	
340.	15-4	Engine gear	
341.	15-5	Fuel control unit	
342.	15-6	RH MLG axle lever assembly	
343.	15-7	Engine fuel pump	
344.	15-8	Engine oil filter	
345.	15-9	Hydraulic filter unit assembly	
346.	15-10	Turbine disk	
347.	15-11	Hydraulic filter ball	
348.	15-12	MLG planing link	
349.	15-13	Hydraulic filter ball	
350.	15-14	Drive shaft (?)	
351.	15-15	Air turbine starter	467 m out
352.	15-16	AMAD Hydraulic pump	
353.	15-17	MLG hub and brake	SN 2492
354.	15-18	Swash plate type of pump	
355.	15-19	MLG trunnion	
356.	15-20	Power turbine shaft	
357.	15-21	MLG tie down	
358.	15-22	Hot air turbine	
359.	15-23	Centre-line pylon piece	
360.	15-24	NLG attachment pin	
361.	15-25	BRU piece	
362.	15-26	NLG upper trunnion	
363.	15-28	NLG drag brace strut	
364.	15-29	RH LAU-116 fwd ejector foot	
365.	15-30	RH MLG trunnion	
366.	15-31	RH LAU-116 aft ejection foot	
367.	15-32	MLG lower trunnion	560 m out
368.	15-33	Alternator	
369.	15-34	MLG shocker absorber	
370.	15-35	MLG axle	
371.	15-36	Fwd compressor wheel	
372.	16-2	WR attachment bulkhead region	
373.	16-3	Emergency brake accumulator	
374.	16-4	TEF actuator aft attachment point	
375.	16-5	Tail hook actuator	
376.	16-6	NLG launch bar	
377.	16-7	NLG mid section	
	16-8	Photo of launcher tree impact marks	
378.	16-9	NLG Fwd attachment pin	
379.	16-10	MLG door bell crank	
380.	16-11	Gun cam	
381.	16-12	IFR probe tip	
382.	16-13	Hydraulic reservoir manifold	
383.	16-14	WR attach point	
384.	16-15	TEF actuator	
385.	16-16	LEF universal	
386.	16-17	RH WR attachment	
387.	16-18	Upper wing attachment (LH?)	
388.	16-19	Gun breach assembly	
389.	16-20	Gun barrel aft section	
390.	16-21	TEF actuator	
391.	16-22	NWS power unit	
392.	16-23	Seat part	
393.	16-24	LEF torque tube	
394.	16-25	Fwd piece of gun barrel	
395.	16-26	LEX mount	
396.	16-27	Seat part	
397.	16-28	Seat part (safe handle)	
398.	16-29	Canopy mount piece	
399.	16-30	Seat part	
400.	16-31	Seat part	
401.		Gun piece	No tag, No photo
402.	16-32	IFR probe piece	
403.	16-33/34	TEF actuator and bits of perspex canopy	Leading back to crater

Appendix B: Suggested Generic Data Dictionaries

The following are suggested generic Data Dictionaries Add extra themes as dictated after examination of the accident site. Multiple aircraft accidents may result in very large dictionaries. In this case, it may be easier to sort the parts after data collection to avoid confusion in the field.

Fixed wing aircraft

Item classification	Feature type	Comments
Point Generic	Point	Automatically generated
Line Generic	Line	Automatically generated
Area Generic	Area	Automatically generated
Reference feature	Point	Eg: Target. Trees, Power poles
Reference feature	Line	Eg: Fence, Road, Power line
Reference feature	Area	Eg: Buildings. Runway, Dams
Main Wing Right hand	Area	Main Wing RH
Main Wing Left hand	Area	Main Wing LH
Main Wing Parts	Point	Identify left or right if possible
Horizontal Stabiliser	Point	Identify left or right if possible
Vertical Stabiliser	Point	Vertical Tail
Power plant(s)	Area	Main parts of engine(s)
Power system Parts	Point	Identify from which area if possible
Forward Fuselage	Area	Main body of fwd. fuselage
Aft Fuselage	Area	Main body of aft. fuselage
Forward Fuselage	Point	Identify from which area if possible
Aft Fuselage	Point	Identify from which area if possible
Internal stores	Point	Eg: weapons, sensors and cargo
External stores	Point	Eg: weapons, sensors, and fuel tanks
Main Landing gear	Point	Identify left or right if possible
Other Landing gear	Point	Identify left or right if possible
Ground marks	Point	Eg: Dents, spot fire, cut trees, etc.
Ground marks	Line	Eg: Cuts, scrapes, skid marks, etc.
Ground marks	Area	Eg: Craters, fires, fuel marks, etc.
Avionics	Point	Identify if possible
Control surfaces	Point	Identify if possible
Actuators	Point	Identify if possible
Biological & Personal	Point	Personal protective kit, Publications etc.
Witness positions	Point	

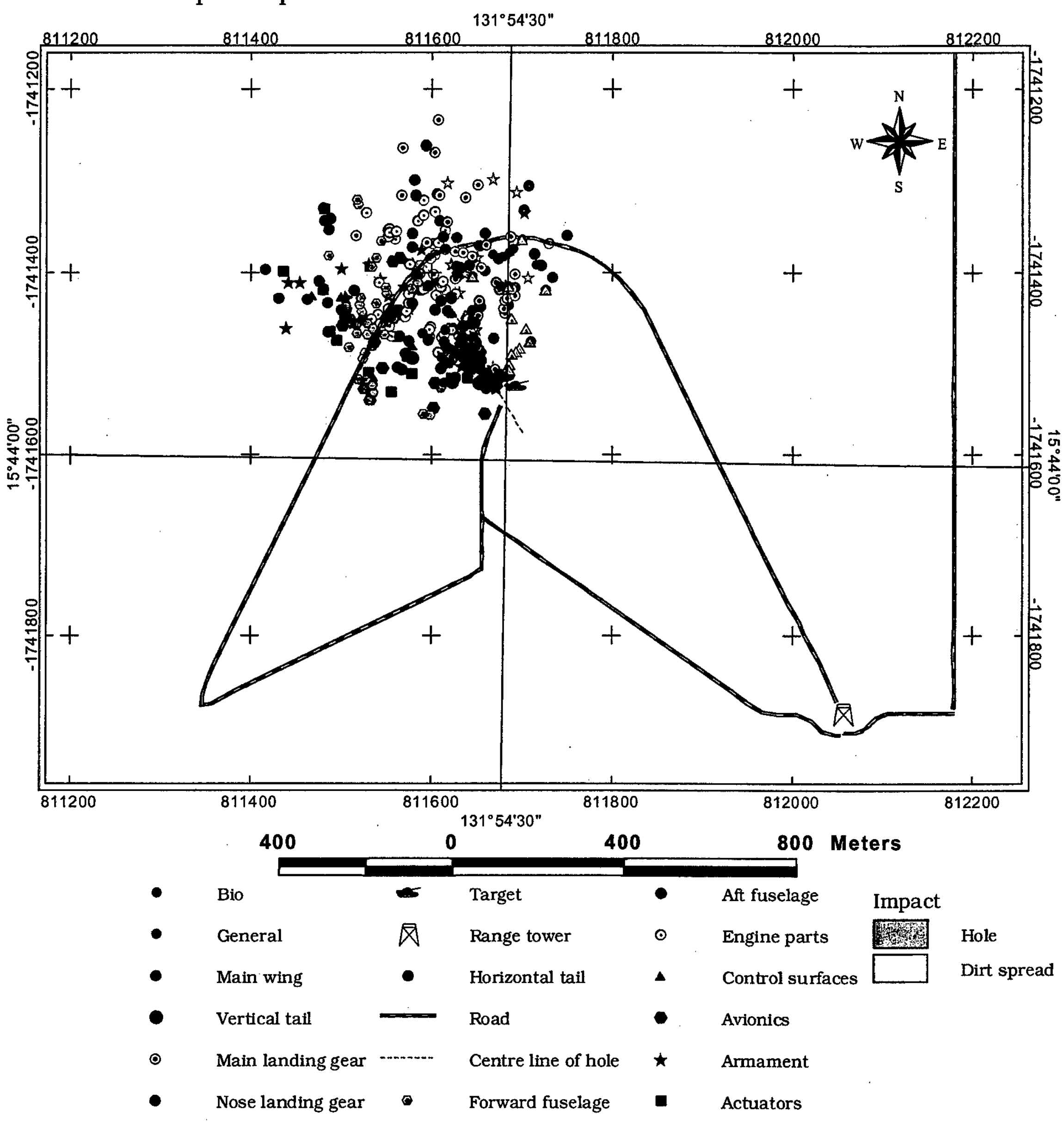
Rotary wing

Point Generic	Point	Automatically generated
Line Generic	Line	Automatically generated
Area Generic	Area	Automatically generated
Reference feature	Point	Eg: Target. Trees, Power poles
Reference feature	Line	Eg: Fence, Road, Power line
Reference feature	Area	Eg: Buildings. Runway, Dams
Main rotor	Area	Blades and hub
Main rotor Parts	Point	Other parts
Tail rotor	Point	Blades, hub and gearbox
Horizontal Stab.	Point	Horizontal Tail, usually with tail boom
Vertical Stab.	Point	Vertical Tail, usually with tail boom
Power plant(s)	Area	Main parts of engine(s)
Power system Parts	Point	Identify engine if possible
Drive train	Point	Drive shafts and gearboxes.
Forward Fuselage	Area	Main body of fwd. fuselage
Aft Fuselage	Area	Main body of aft. Fuselage – tail boom
Forward Fuselage	Point	Identify from which area if possible
Aft Fuselage	Point	Identify from which area if possible
Internal stores	Point	Eg: weapons, sensors and cargo
External stores	Point	Eg: weapons, sensors, and fuel tanks
Main Landing gear	Point	Identify left or right if possible
Other Landing gear	Point	Identify left or right if possible
Ground marks	Point	Eg: Dents, spot fire, cut trees, etc.
Ground marks	Line	Eg: Cuts, scrapes, skid marks, etc.
Ground marks	Area	Eg: Craters, fires, fuel marks, etc.
Avionics	Point	Identify if possible
Control surfaces	Point	Identify if possible
Actuators	Point	Identify if possible
Biological & Personal	Point	Personal protective kit, Publications etc.
Witness positions	Point	

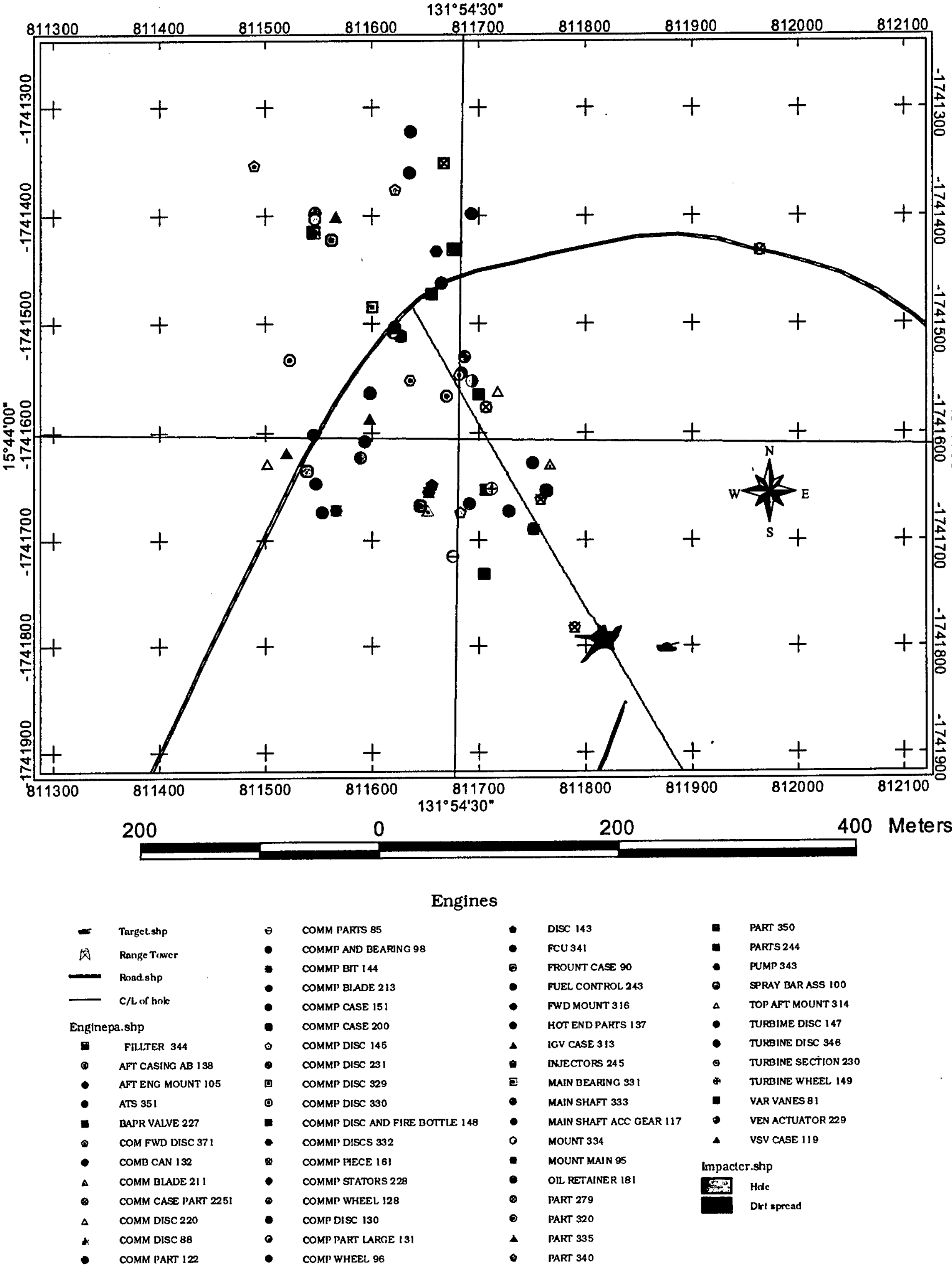
Appendix C: Maps

Various examples of maps produced.

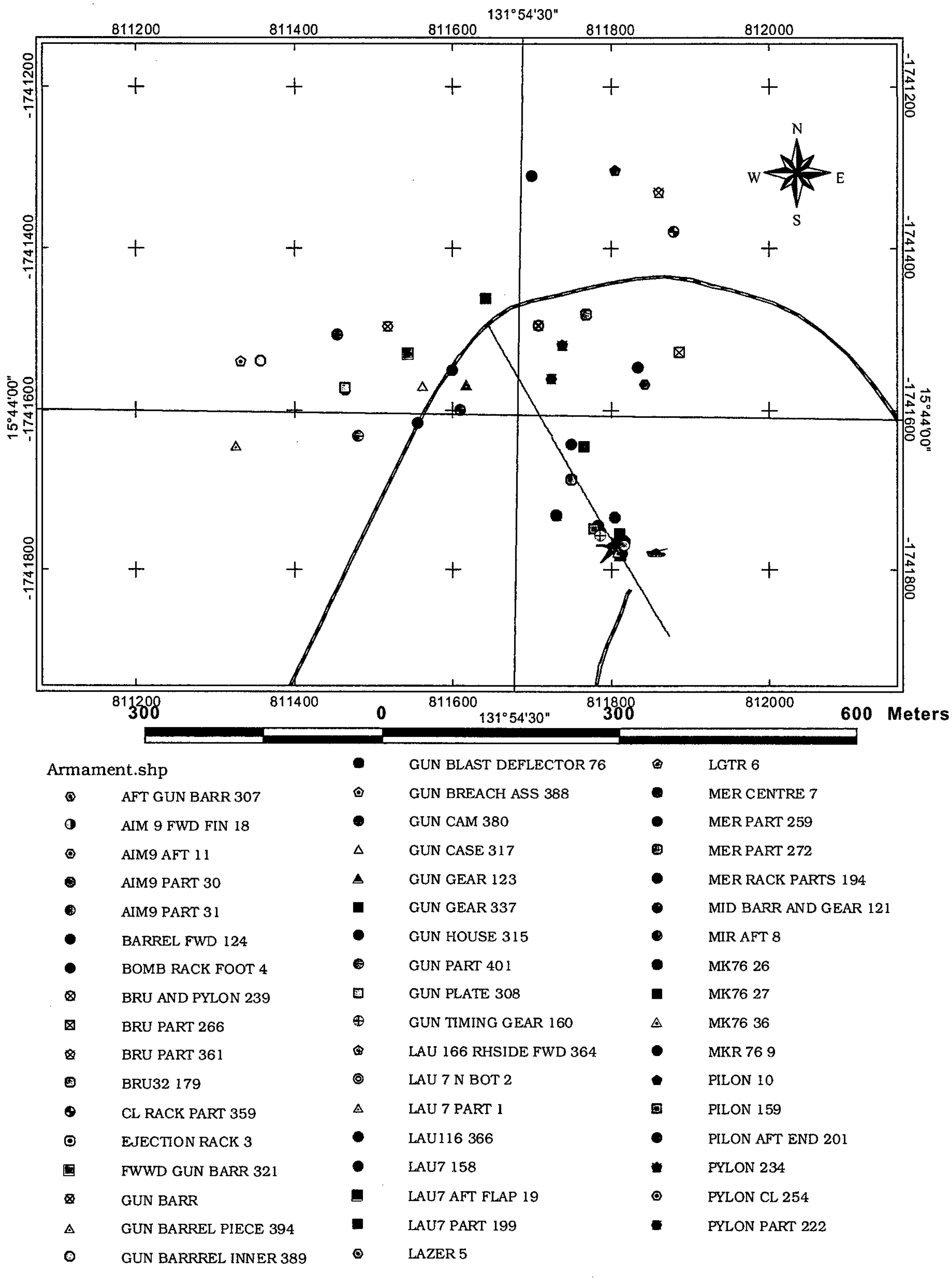
General map of all points



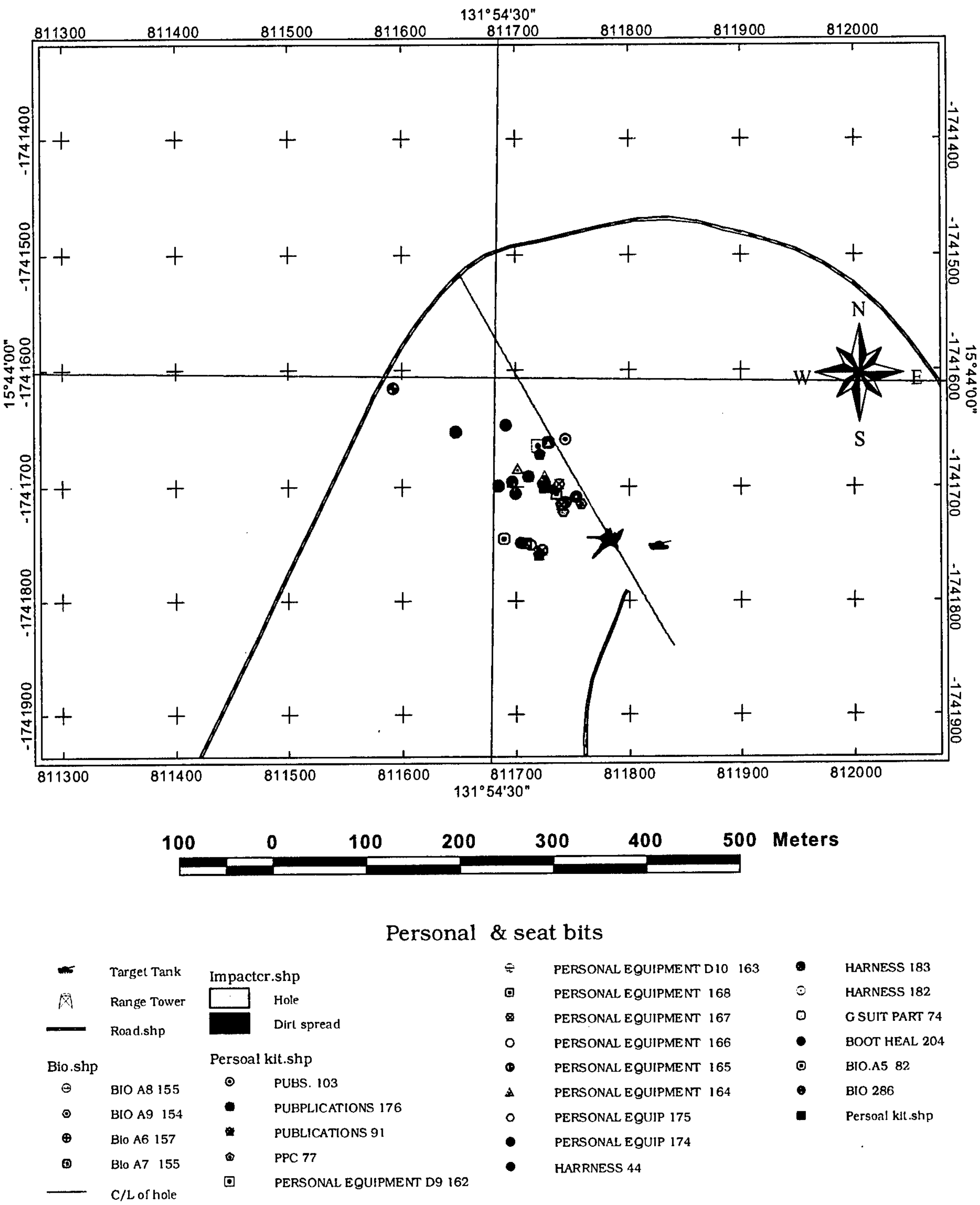
Engine parts with the legend showing each part identified



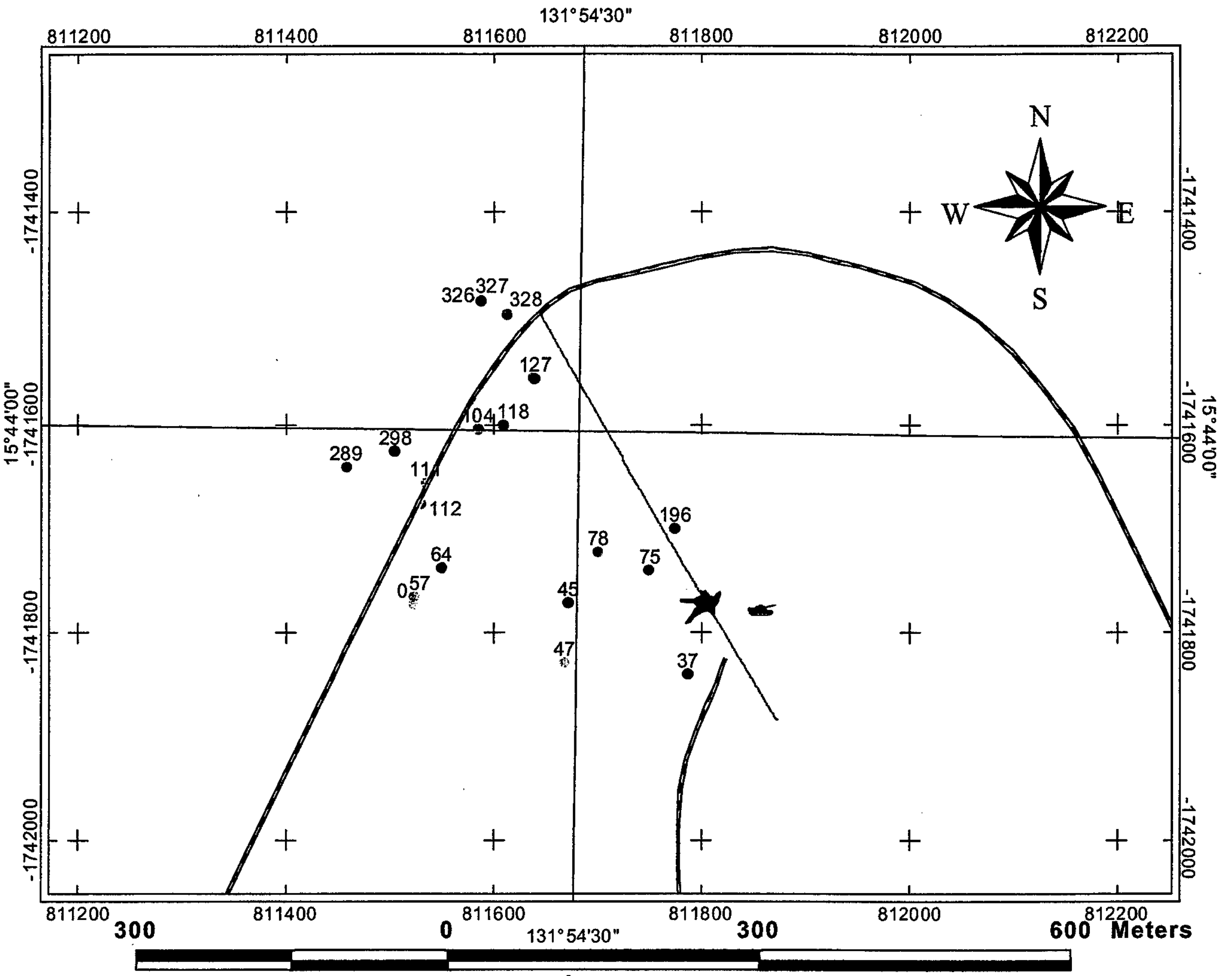
Armament parts. In this case the legend has each part identified



Engine parts. The parts are identified in the list attached.



The avionics parts with labels showing the photograph No.

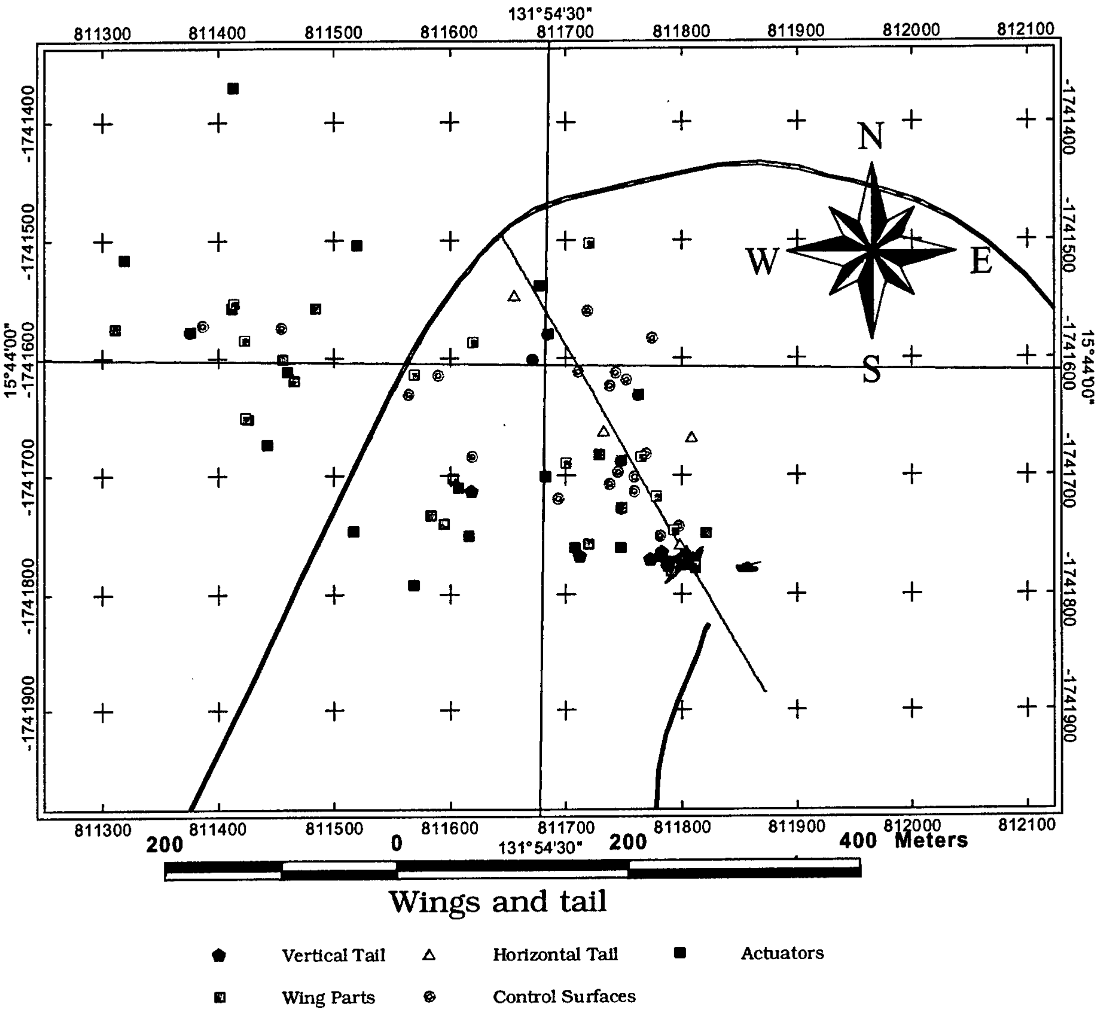


Avionics

Avionics.shp

- ADI BALL HUD PART 78
- BITS RELAYS 127
- BOX AND BITS 289
- CABLES 64
- CB BITS 111
- CB PNL 298
- IFR PROBE 118
- PLUGS
- RAD 37
- RADOME COMP 196
- UK 104
- UK 75
- UK GAUGE 112
- UKN 326
- UKN 327
- UKN 328
- UNKNOWN 57
- WAVE GUIDE AND WIRES 47
- WIRES 45

Aerodynamic surfaces and associated parts showing their trend to the north west of the aircraft line of travel.



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No Limitations

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18. DEFTEST DESCRIPTORS

DGPS, GPS, Aircraft accident investigation, Wreckage plotting, GIS, Wreckage mapping, Global Positioning System, Geographical information system, Aircraft accident.

19. ABSTRACT

On August 20, 1998 a United States Marine Corps F/A-18 aircraft crashed at Delamere bombing range in the Northern Territory. AMRL was invited to aid in the investigation by trialing the AMRL wreckage mapping and analysis equipment at the site. The equipment was used to plot and record all wreckage of interest. Maps of the wreckage were produced on site and handed over to the accident investigation team. These rapidly produced maps, along with the experience brought with the AMRL investigators with on site wreckage examination, greatly aided the accident investigation team to expedite recovery of the site and clarify many aspects of the accident. To this end, the trial of the equipment was very successful. Following this trial, the data was used to explore the capabilities of other visualisation software, and its relevance to accident investigation. The results of this are presented during the discussion of the accident.

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